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Gender and Youth Inclusion in E-Crop-Based Agripreneurship

Rita Fredericks

Abstract

Agriculture is also experiencing a digital revolution with new platforms such as E-Crop that can help farmers deal with information, track crops, and gain real-time advisory services. But such technologies can only reach their maximum potential if women and youth, who make up a large percentage of the agricultural workforce, are included. This paper discusses the significance of gender and youth participation in e-crop-based agripreneurship, identifies challenges they encounter, and offers strategies for promoting inclusive involvement in digital agriculture.

Introduction

Agriculture continues to form the backbone of most developing economies, supporting the livelihood of millions. However, conventional farming is plagued by many issues climate change, decreased soil fertility, and poor access to information. The availability of E-Crop systems, electronic platforms that combine data acquisition, crop monitoring, and decision aid tools, presents an opportunity to revolutionize agriculture. However, technology adoption often reflects social inequalities, where women and rural youth remain marginalized. Inclusion in E-Crop-based agripreneurship a combination of electronic crop management and agricultural entrepreneurship is vital for sustainable rural development. By engaging women and youth as active stakeholders, digital agriculture can become a powerful tool for economic empowerment and innovation.

Understanding E-Crop-Based Agripreneurship

E-Crop-based agripreneurship incorporates information and communication technology (ICT) tools in crop production, marketing, and management. Farmers make informed decisions through mobile applications, drones, IoT sensors, and cloud-based data platforms to improve productivity and profitability.

Important components are

Digital crop management: Planting, irrigation, pest management, and monitoring through mobile applications.

Market linkage: Direct linkages of farmers with buyers and minimizing middlemen.

Financial access: Providing digital payments, microloans, and insurance services.

Sharing knowledge: Offering real-time advisory on crop health, weather conditions, and optimal management practices.

When coupled with entrepreneurship, this model enables individuals particularly youth and women to start agri-tech startups, run data-driven farms, and provide digital services to farmers in the

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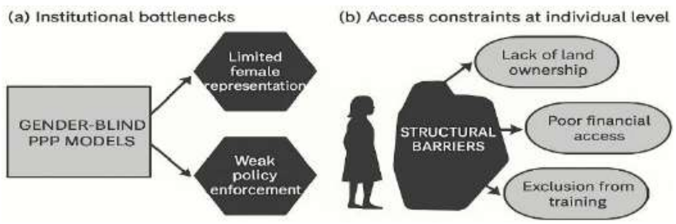
vicinity.



Source: https://www.mdpi.com

The Role of Women in E-Crop Agripreneurship

Women's Contribution to Agriculture: Across the world, women make up close to 43% of the farm labor force (FAO, 2022). They have vital roles to play in planting, weeding, harvesting, and post-harvest handling in rural India. They are, however, mostly denied access to land, credit, technology, and training.

Challenges Confronted by Women: Digital literacy deficit: Women lack smartphone access, internet coverage, and technical education.

Socio-cultural barriers: Gender constraints limit their involvement in decision-making and entrepreneurship.

Financial exclusion: Restricted credit, collateral, and access to financial institutions hamper agripreneurial enterprises.

Empowering Women through E-Crop Platforms

E-Crop platforms can act as equalizers by:

- ✓ Providing cost-effective, local-language interfaces for women farmers.
- ✓ Offering online courses and digital literacy for women.
- ✓ Enabling women-led cooperatives that deal with data and offer advisory services to smallholders.
- ✓ Inspiring women agripreneurs to create digital solutions for their localities, like e-marketing platforms or precision farming instruments.

If women access digital resources and acquire agripreneurial competencies, family incomes, food security, and local resilience increase substantially.

Youth Involvement in E-Crop Agripreneurship

Youth Inclusion Requirement: The age of farmers is increasing across the world, with fewer youths pursuing agriculture as a profession. E-Crop-driven agripreneurship presents a contemporary, technology-focused image of farming that can entice youth back into agriculture. By incorporating digital technologies, young people can discover innovative opportunities in:

- ✓ Smart farming services (drone operation, soil mapping, weather analytics).
- ✓ Agri-data management and consulting.
- ✓ E-commerce and supply chain innovations.
- ✓ Agri-fintech and digital advisory start-ups.

Barriers for Youth

- ✓ Access to capital and credit for agribusiness initiation is limited.
- ✓ Training and mentoring for digital tools and agribusiness management.
- ✓ Poor connectivity between education systems and agricultural entrepreneurship ecosystems.

Empowerment Strategies: Incorporation of E-Crop modules in agricultural studies for developing digital competencies. Youth innovation hubs and incubation centers for agri-startups. Offering soft loans and incentives for youth entrepreneurship in digital agribusiness. Fostering public–private partnerships (PPPs) that link youth innovators with investors and government programs. Youth and gender inclusion guarantee that agriculture becomes more dynamic, data-driven, and sustainable.

Policy and Institutional Support

Strong institutional systems are needed to support gender and youth inclusion in E-Crop-based agripreneurship.

Major policy suggestions are:

Capacity Building Programs: Government and NGOs should conduct routine training on digital farming technologies among women and youth.

Financial Inclusion: Design gender-sensitive credit programs and low-interest loans for agritech startups.

ICT Infrastructure: Increase rural internet penetration and low-cost smartphone availability.

Incentives for Digital Adoption: Offset digital gear such as sensors, drones, and software for small farmers.

Collaboration and Networking: Promote cooperation among universities, research centers, and private agri-tech firms.

These steps can build an enabling environment where technology becomes a bridge between promise and possibility.

Conclusion

E-Crop-based agripreneurship is the future of digital agriculture, combining technology, entre-preneurship, and sustainability. To utilize its full potential, women's and youth active engagement is a necessity. Equipping them with digital literacy, financial inclusion, and institutional support will not only enhance agricultural productivity but also create jobs, build rural economies, and improve climate resilience. Gender and youth-friendly e-crop models have the potential to make agriculture a dynamic, inclusive, and lucrative business that benefits all farmers, irrespective of their age or gender.

References

FAO (2022). The State of Food and Agriculture: Women in Agriculture.

Ministry of Agriculture and Farmers' Welfare (2023). Digital Agriculture Mission Report.

World Bank (2021). Youth in Agriculture: Digital Pathways to Employment.

UNDP (2020). Empowering Rural Women through ICT in Agriculture.

ICAR (2024). E-Crop and Smart Farming Initiatives in India.

Economic Impact Assessment of E-Crop Technologies in Precision Farming

Rita Fredericks and Sweta Jha

Abstract

Precision farming, supported by E-crop technologies, has transformed conventional agriculture into a data-driven, efficient, and sustainable enterprise. By enabling farmers to optimize resource use, reduce input costs, and increase yields, these technologies have shown profound economic benefits. This article evaluates the economic impact of E-crop technologies including GPS, GIS, drones, sensors, Internet of Things (IoT), Artificial Intelligence (AI), and Decision Support Systems (DSS) in precision agriculture. It also highlights challenges, case studies, and future prospects for maximizing profitability and sustainability in farming systems.

Introduction

Agriculture is the backbone of global food security, yet it faces enormous challenges from rising input costs, climate variability, and labor shortages. Traditional farming practices, characterized by uniform input application and limited data use, often lead to inefficiencies and reduced profitability. To overcome these challenges, E-crop technologies have emerged as a revolutionary approach within precision farming. Precision farming focuses on applying the right input, at the right time, in the right place and in the right amount. E-crop technologies comprising digital tools and automated systems facilitate precise decision-making by collecting and analyzing real-time field data. These innovations not only enhance productivity but also bring substantial economic advantages, such as reduced input wastage improved resource efficiency, and higher profit margins. This article provides a detailed economic assessment of how E-crop technologies are reshaping modern agriculture and ensuring financial sustainability for farmers.

Source: https://www.researchgate.net

Understanding E-Crop Technologies in Precision Farming

E-crop technologies refer to digital tools and smart systems that collect, analyze, and interpret data

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to support site-specific and real-time farm management decisions. The major components include:

Geographic Information System (GIS) and Global Positioning System (GPS): GIS and GPS enable precise field mapping and georeferenced data collection, allowing accurate variable-rate application of fertilizers, seeds and pesticides reducing waste and maximizing efficiency.

Remote Sensing and Drones: Drones equipped with multispectral cameras monitor crop health, detect nutrient deficiencies, and assess pest or disease outbreaks early, enabling cost-effective management interventions.

Internet of Things (IoT) and Sensors: IoT devices monitor soil moisture, temperature, and nutrient levels, helping farmers make data-driven irrigation and fertilization decisions that reduce costs and increase returns.

Artificial Intelligence (AI) and Machine Learning (ML): AI algorithms analyze complex data sets to predict yield outcomes, optimize input use, and automate decision-making processes, enhancing farm profitability.

Decision Support Systems (DSS): Software platforms integrate data from multiple sources to guide farm-level decisions, minimizing uncertainty and improving economic returns.

Economic Benefits of E-Crop Technologies

The adoption of E-crop technologies offers several direct and indirect economic benefits for farmers, agribusinesses, and the broader agricultural sector.

Input Cost Reduction: Precision input application minimizes wastage of fertilizers, water, and pesticides. Studies show savings of 15-30% in fertilizer costs and 20-40% in pesticide use through site-specific management.

Increased Crop Productivity and Yield: E-crop tools optimize input timing and dosage, leading to 10-25% yield improvement depending on the crop and region. Accurate monitoring ensures better plant health and resource use efficiency.

Enhanced Resource-Use Efficiency: By aligning inputs with field conditions, these technologies improve nutrient-use efficiency (NUE), water-use efficiency (WUE), and energy efficiency, thereby reducing operational costs.

Labor and Time Savings: Automation through robotics and AI reduces dependency on manual labor, which is especially beneficial in regions facing labor shortages. Farmers save both time and money through remote monitoring and management.

Risk Reduction and Decision Accuracy: Predictive analytics and real-time monitoring minimize uncertainties related to weather, pests, and diseases helping farmers make timely, cost-effective interventions.

Market Competitiveness and Profitability: Adoption of E-crop systems enhances product quality and consistency, giving farmers a competitive edge in high-value markets and increasing profitability per hectare.

Economic Assessment Framework

The economic impact of E-crop technologies can be evaluated through the following parameters:

Cost-Benefit Analysis (CBA): Compares technology investment costs (e.g., sensors, drones, software) against returns from yield improvement and input savings.

- ✓ **Return on Investment (ROI):** ROI helps assess profitability. A typical ROI of 20-40% is reported within 2-3 years of adopting E-crop systems in intensive cropping systems.
- ✓ **Net Present Value (NPV):** Long-term economic viability is assessed using discounted cash flow methods, reflecting cumulative benefits over several years.
- ✓ **Payback Period:** Farmers can recover initial investments in 2-4 years, depending on scale and crop type.
- ✓ **Economic Efficiency Indicators:** Indicators like Gross Margin, Benefit-Cost Ratio (BCR), and Production Efficiency demonstrate overall improvement in farm economics.

Case Studies

Precision Nutrient Management in India: Farmers using Nutrient Expert® and GPS-based fertilizer application in rice-wheat systems reported 15% fertilizer savings and 12% yield increases, translating to higher profits.

Drone-Assisted Spraying in Maize Fields (China): Drone spraying reduced pesticide costs by 30% and labor time by 60%, enhancing net income and worker safety.

IoT-Based Smart Irrigation in Israel: IoT-controlled irrigation systems saved 25-35% water and improved yields by 20%, demonstrating the economic and environmental value of precision irrigation.

AI-Powered Yield Prediction in Europe: AI models forecasting yield trends allowed farmers to plan input use and market sales better, increasing overall profitability by 10-15%.

Challenges in Economic Adoption

Despite the benefits, several challenges limit the economic adoption of E-crop technologies. High initial investment and limited access to capital hinder small farmers. Low digital literacy and data integration issues restrict effective use. Uncertain ROI, especially on small farms, reduces confidence in adoption. Policy gaps, inadequate infrastructure, and weak internet connectivity further delay progress. Addressing these through subsidies, training, and cooperative-based models is vital for inclusive growth.

Environmental and Socioeconomic Spillover Effects

E-crop technologies provide not only direct economic gains but also significant environmental and social benefits. Environmentally, they enhance sustainability by reducing fertilizer runoff, conserving resources, and lowering greenhouse gas emissions. Socially, they empower rural communities through new skilled job opportunities and digital inclusion. Improved market linkages and transparent, data-driven supply chains strengthen farmer-buyer relationships. Overall, precision farming supports sustainable rural development and inclusive agricultural growth.

Future Prospects

The future of precision farming depends on integrating cutting-edge technologies to enhance efficiency and sustainability. Artificial Intelligence and robotics will enable autonomous operations and predictive analytics, while satellite-based E-crop platforms will support large-scale monitoring. Blockchain will ensure transparency and fair trade, and nano-fertilizers will boost nutrient efficiency. Strengthening public-private partnerships will expand innovation access. As digital agriculture advances, data-driven decisions will underpin profitable, climate-smart, and sustainable farming.

Conclusion

E-crop technologies in precision farming have shown significant economic benefits by reducing input costs, increasing yields, and improving resource efficiency. Despite challenges such as high investment and limited accessibility, the long-term advantages surpass initial expenditures. Economic assessments confirm that integrating digital tools enhances productivity, profitability, and sustainability. For inclusive growth, collaboration among governments, research institutions, and the private sector is essential to provide training, subsidies, and technical support, making E-crop technologies vital for food security and sustainable agriculture in the 21st century.

References

Borghi, E., Avanzi, J. C., Bortolon, L., Junior, A. L. and Bortolon, E. S. (2016). Adoption and use of precision agriculture in Brazil: Perception of growers and service dealership. *Journal of Agricultural Science*, 8(11): 89-104.

Ifeanyichukwu, H. I. and Aneke, V. I. (2020). Prospect of Precision Agriculture in Nigerian Economy. *Journal of Inventive Engineering and Technology*, 1(2).

Nabara, I. S. and Man, N. (2025). Enhancing Precision Farming Innovations for Global Food Security through Agricultural Extension Services. In Advancing Global Food Security With Agriculture 4.0 and 5.0 (pp. 119-142). IGI Global Scientific Publishing.

Yao, H., Huang, Y., Tang, L., Tian, L., Bhatnagar, D. and Cleveland, T. E. (2018). Using hyperspectral data in precision farming applications. In Advanced Applications in Remote Sensing of Agricultural Crops and Natural Vegetation (pp. 3-35). CRC Press.

Site-Specific Nutrient Management Supported by E-Crop Technologies

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Abstract

Site-Specific Nutrient Management (SSNM) marks a major shift in agronomy, focusing on precise nutrient application tailored to soil and crop needs. With digital E-crop technologies like GIS, GPS, remote sensing, IoT, and decision-support tools, farmers can enhance nutrient efficiency, boost productivity, and reduce environmental harm. SSNM integrates technology and sustainability to revolutionize modern nutrient management in agriculture.

Introduction

Nutrient management is a cornerstone of modern crop production. Traditionally, fertilizers were applied uniformly across fields, assuming homogeneity in soil fertility and crop nutrient demand. However, in reality, soils are highly variable in their physical, chemical, and biological properties. This spatial variability results in either nutrient deficiency or excess in different parts of a field, leading to yield loss, resource wastage, and environmental pollution. Site-Specific Nutrient Management (SSNM) is a science-based approach that recognizes these spatial and temporal variations. It involves precise nutrient application tailored to specific field zones or even individual plants. The integration of E-crop technologies including precision sensors, drones, mobile-based advisory systems, and cloud-based nutrient mapping has made SSNM a practical and scalable approach for modern farmers. The main goal of SSNM is to provide the right nutrient, at the right rate, at the right time, and in the right place a principle known as the 4R Nutrient Stewardship.

Concept and Principles of Site-Specific Nutrient Management

SSNM aims to ensure optimal nutrient supply that matches the crop's demand during its growth stages while reducing losses to the environment. Its key principles include:

Source: https://www.slideshare.net

Understanding Field Variability: Soil fertility varies across short distances due to differences in texture, organic matter, topography, and management history. Identifying these variations is the first step in SSNM.

Customized Nutrient Application: Based on soil and crop data, fertilizers are applied variably rather

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than uniformly, improving efficiency.

Integration of Soil and Crop Sensors: Real-time sensors measure soil nutrient status and crop health to guide fertilization decisions.

Dynamic Decision-Making: SSNM is not static; it involves continuous monitoring and adjustment of nutrient inputs according to changing crop requirements and environmental conditions.

Sustainability Focus: It balances productivity with ecological integrity by minimizing nutrient losses and reducing greenhouse gas emissions.

Role of E-Crop Technologies in SSNM

The success of SSNM is largely dependent on advanced E-crop technologies that collect, analyze, and interpret data to support precise nutrient management decisions. The major technologies include:

Geographic Information System (GIS) and Global Positioning System (GPS): GIS and GPS allow spatial mapping of soil fertility, crop yields, and nutrient application zones. With GPS-guided machinery, fertilizers can be applied with centimeter-level precision, ensuring uniform distribution only where needed.

Remote Sensing and Drones: Multispectral and hyperspectral imaging from drones and satellites help identify nutrient deficiencies by analyzing crop canopy color, vigor, and chlorophyll content. These images can generate nutrient prescription maps for variable-rate fertilization.

Internet of Things (IoT) and Smart Sensors: IoT-enabled soil and plant sensors continuously record parameters like soil moisture, pH, nitrogen levels, and temperature. This data is transmitted to a cloud platform for real-time nutrient recommendations.

Decision Support Systems (DSS) and Mobile Applications: Software platforms like Nutrient Expert®, Agro Sense®, and mobile-based advisory apps help farmers make informed nutrient management decisions based on site-specific data and local recommendations.

Big Data and Artificial Intelligence (AI): AI algorithms analyze vast datasets from multiple farms to predict nutrient requirements, optimize fertilizer timing, and identify patterns of nutrient deficiencies. Machine learning models help in predictive nutrient mapping and precision recommendations.

Components of SSNM Framework

The practical implementation of SSNM involves several steps:

Soil Sampling and Analysis: Collection of georeferenced soil samples to determine nutrient content (N, P, K, micronutrients).

Crop Growth Monitoring: Using sensors and drone imagery to monitor crop nutrient uptake and detect deficiencies.

Yield Mapping: Yield monitors attached to harvesters record yield variations, helping identify underperforming zones.

Variable Rate Application (VRA): GPS-controlled applicators deliver fertilizers at variable rates according to prescription maps.

Feedback and Data Integration: Continuous feedback from sensors and field observations helps refine future nutrient management strategies.

Benefits of SSNM Supported by E-Crop Technologies

Implementing SSNM with E-crop technologies offers multiple agronomic, economic, and environmental benefits:

Enhanced Nutrient Use Efficiency: Nutrients are applied where and when needed, reducing losses and improving fertilizer efficiency.

Higher Crop Productivity: Optimal nutrient availability leads to improved crop growth, yield, and quality.

Reduced Input Costs: Farmers save money by avoiding unnecessary fertilizer application.

Environmental Protection: Reduces leaching, runoff, and greenhouse gas emissions associated with excess fertilizer use.

Data-Driven Decision Making: Real-time insights help farmers make informed nutrient management decisions.

Adaptation to Climate Change: Precision nutrient management enhances crop resilience to stress and variable weather.

Case Studies and Applications

Rice-Wheat System in India: The Nutrient Expert® decision support tool has successfully guided SSNM in rice-wheat systems across the Indo-Gangetic Plains, improving yields by 10-15% and saving 15-20% fertilizers.

Maize and Sugarcane Precision Farming: Drone-based NDVI (Normalized Difference Vegetation Index) imaging helps detect nitrogen stress early, allowing timely interventions.

European Smart Farming: In countries like Germany and the Netherlands, IoT-based soil nutrient sensors and AI models have revolutionized fertilizer management, improving sustainability metrics.

Challenges in Implementation

Despite its advantages, several barriers limit large-scale adoption:

- ✓ High cost of sensors, drones, and precision equipment.
- ✓ Limited technical skills among farmers.
- ✓ Data management and interoperability issues.
- ✓ Lack of reliable internet connectivity in rural areas.
- ✓ Need for policy and institutional support for technology dissemination.

Future Prospects

The future of SSNM depends on integrating AI, robotics, and satellite-based E-crop platforms to enhance precision and sustainability. Innovations such as nano-fertilizers for controlled nutrient release, autonomous robots for targeted fertilizer placement, and cloud-based platforms for real-time decision-making will drive efficiency. Blockchain will ensure transparency and traceability. As digital infrastructure grows, SSNM will be vital for sustainable intensification and improved soil and ecosystem health.

Conclusion

Site-Specific Nutrient Management supported by E-crop technologies represents the future of sustainable agriculture. By precisely matching nutrient supply to crop demand, SSNM enhances productivity, reduces costs, and protects the environment. Integrating GIS, remote sensing, IoT, and AI-driven systems enables smarter decisions at the field level. To fully realize its potential, governments, researchers, and private sectors must collaborate to make these technologies affordable, accessible, and farmer-friendly. A balanced combination of science, technology, and farmer participation will ensure nutrient-smart, climate-resilient agriculture for future generations.

References

Jauhari, S., Minarsih, S., Hindarwati, Y., Pramono, J., Susila, A., Sudarto, S., ... and Samijan, S. (2025). Rice yield enhancement and environmental sustainability with precision nutrient management. *Global Journal of Environment Science and Management*, 77-92.

Karri, V. and Nalluri, N. (2024). Enhancing resilience to climate change through prospective strategies for climate-resilient agriculture to improve crop yield and food security. *Plant Science Today*, 11(1): 21-33.

Stettmer, M., Mittermayer, M., Maidl, F. X., Schwarzensteiner, J., Hülsbergen, K. J. and Bernhardt, H. (2022). Three methods of site-specific yield mapping as a data source for the delineation of management zones in winter wheat. *Agriculture*, 12(8): 1128.

Jat, R. K., Meena, V. S., Durgude, S., Sohane, R. K., Jha, R. K., Kumar, A., ... and Lenka, A. K. (2025). Bridging the gap: challenges and adoption of climate-resilient agriculture technologies in agricultural landscapes across agro-climatic zones of Bihar, India. *Frontiers in Sustainable Food Systems*, 8: 1504388.

Superweeds and Rising Herbicide Resistance: New Strategies for Weed Control

Neelkamal Mishra, Anil Kumar and Rita Fredericks

Abstract

The emergence of superweeds weeds species resistant to multiple herbicides poses a major global threat to food security. Overreliance on chemical weed control has accelerated herbicide resistance, reducing herbicide effectiveness and crop productivity. This article explores the causes, impacts, and major resistant weed species while highlighting new weed management strategies, including integrated weed management (IWM), biotechnology, robotics, and precision farming. Sustainable, technology-integrated approaches are essential for long-term weed control and agricultural resilience.

Introduction

Weeds compete with crops for nutrients, water, light, and space, greatly decreasing yield and quality. Herbicides have long transformed the history of agriculture by providing effective and cost-saving weed control. But decades of sustained herbicide application, frequently using the same mode of action, have resulted in the selection for resistant weed populations so-called superweeds. As reported by the Herbicide Resistance Action Committee (HRAC), over 500 distinct instances of herbicide-resistant weeds have been documented worldwide, infesting more than 250 species. India also experiences growing resistance issues, especially among major crops like rice, wheat, maize, and soybean. Emergence of superweeds erodes the sustainability of contemporary agriculture. Hence, new approaches to integrated, ecological and technological solutions to redeem effective weed control are imperative on an urgent basis.

Source: https://grist.org

Superweeds and Herbicide Resistance

Definition of Superweeds: Superweeds are weed species that are resistant to one or more herbicide modes of action and which, thereby, can tolerate chemical control measures that would otherwise be fatal. Such resistance is the result of evolutionary selection pressure resulting from continual use of

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herbicides.

Mechanisms of Resistance

Resistance to herbicides develops through a number of mechanisms:

Target-site resistance (TSR): Mutations in the genes of the herbicide's target enzyme prevent it from binding and being deactivated.

Non-target-site resistance (NTSR): Overactive metabolic processes detoxify or sequester herbicides before they are able to act.

Cross-resistance: One mechanism of resistance to several herbicides that share the same mode of action.

Multiple resistance: The population of weeds becomes resistant to herbicides with diverse mechanisms at the same time.

Key Superweeds Globally

Some of the globally accepted superweeds are:

***Amaranthus palmeri* (Palmer amaranth):** Resistant against glyphosate and ALS inhibitors.

***Lolium rigidum* (Rigid ryegrass):** Resistant to over 12 classes of herbicides.

***Echinochloa colona* (Jungle rice):** Pancontinental resistance in Asian rice biota.

***Conyza canadensis* (Horseweed):** Glyphosate- and paraquat-resistant.

***Phalaris minor* (Canary grass):** Dominant glyphosate- and isoproturon-resistant weed in Indian wheat crops.

Causes and Impacts of Increased Herbicide Resistance

Causes

Chronic monocropping: Lack of crop rotation promotes the growth of certain weed species.

Overuse of herbicides: Sole reliance on chemical control without incorporating other approaches.

Consecutive employment of the same herbicide mode of action: Amplifies selection pressure on weed populations.

Insufficient monitoring: Inadequate field observation permits resistant populations to disperse undetected.

Inadequate dose or timing: Employing sub-lethal herbicide doses promotes resistance emergence.

Effects

- ✓ Efficacy decline of current herbicides, which results in increased cost and reduced yield.
- ✓ Increased production costs due to the additional application of herbicides or mechanical weeding.
- ✓ Environmental risk, since farmers tend to use higher rates or blends of herbicides.
- ✓ Risk to food security, especially in poor countries that are heavily dependent on chemical weed management.
- ✓ Lower profitability, since herbicide-resistant weeds are more difficult and expensive to manage.

New Strategies for Weed Control

Managing herbicide resistance calls for holistic, science-driven and sustainable weed management strategies. New solutions blend conventional agronomic knowledge with innovative technology.

Integrated Weed Management (IWM)

IWM focuses on integrating a variety of weed control approaches to minimize reliance on herbicides.

Major elements are

Traditional cultural practices: Rotation of crops, intercropping, and deployment of competitive crop cultivars.

Mechanical control: Tillage, hoes, and hand weeding where possible.

Biological control: Use of natural enemies like pathogens, insects, and grazing animals.

Chemical rotation: Rotating herbicides having different modes of action to slow down resistance development.

Cover cropping and mulching: Inhibits weed emergence and improves soil health.

Herbicide Rotation and Mixtures

Alternating or rotation of herbicides with diverse modes of action (MOA) minimizes the opportunity for resistance development. The HRAC system assists farmers in making planning rotation schedules that avoid excessive application of one herbicide group.

Solutions Based on Biotechnology

Transgenic crops: Herbicide-tolerant (HT) crops like glyphosate-tolerant maize or soybean provide flexible weed management.

Gene editing (CRISPR-Cas9): Has the potential to create crops resistant to multiple stress factors while incorporating new genes of weed control.

RNA interference (RNAi) technology: Specific weed genes causing herbicide resistance are targeted.

Bioherbicides: Plant or microbial preparations that kill weeds with minimal environmental effect.

Precision and Smart Farming Equipment

Drones and AI-powered imaging: Identify weeds early using hyperspectral cameras and AI algorithms.

Robotic weeders: Autonomous mechanical devices remove or spot-spray weeds with precision.

GPS-guided sprayers: Apply herbicides accurately and reduce wastage.

Data-driven decision support systems: Assist farmers in planning weed control from real-time field data.

Allelopathy and Natural Weed Suppression

Some plants emit allelopathic chemicals that suppress weed germination and growth. For example, wheat, sorghum, and rice residues have natural herbicidal chemicals that can be leveraged in sustainable weed management systems.

Soil Health and Microbial Management

Balanced microbial communities in healthy soils have the ability to suppress weed seed germination naturally. Organic amendments, composts, and biochar increase soil biodiversity, and therefore indirectly contribute to weed suppression.

Sustainable Weed Control for the Future

Future sustainable weed control must shift from reactive herbicide use to proactive, ecosystem-based approaches. Key principles include diversifying control methods, using digital tools for monitoring and early detection, educating farmers on IWM and herbicide stewardship, and promoting supportive policies. Collaborative research and public-private partnerships are vital for developing region-specific, innovative, and environmentally safe weed management solutions.

Case Studies

Case 1: Phalaris minor in North India: Wheat-rice rotation and excessive use of isoproturon resulted in Phalaris minor developing widespread resistance. Crop diversification (maize, berseem, and pulses), new herbicide molecules (clodinafop, pinoxaden), and mechanical seed drills restored productivity.

Case 2: Amaranthus palmeri in the USA: This weed became resistant to glyphosate in cotton and soybean crops. Farmers used cover cropping, mechanical weeding, and herbicide rotation, achieving more than 70% reduction in density of weeds.

Conclusion

The rise of superweeds resistant to herbicides poses a major challenge to modern agriculture. Overreliance on chemicals has triggered an evolutionary battle farmers are losing. Sustainable weed control requires integrating biological, cultural, mechanical, and digital methods with policy, education, and innovation. Combining Integrated Weed Management, precision agriculture, and biotechnology ensures long-term control while safeguarding the environment and human health.

References

Beckie, H. J., Ashworth, M. B. and Flower, K. C. (2019). Herbicide resistance management: recent developments and trends. *Plants*, 8(6): 161.

Brown, H. C. (2021). Attack of the Superweeds. *The New York Times Magazine*, 26-L.

Damalas, C. A. and Koutroubas, S. D. (2024). Herbicide resistance evolution, fitness cost, and the fear of the superweeds. *Plant Science*, 339: 111934.

Ofosu, R., Agyemang, E. D., Márton, A., Pásztor, G., Taller, J. and Kazinczi, G. (2023). Herbicide resistance: managing weeds in a changing world. *Agronomy*, 13(6): 1595.

Production Technology of Taro

Manish Kumar, Manpreet Kour, Sanjay Singh and Satyapal Singh

Introduction

Colocasia (*Colocasia esculenta* L.), also known as Taro, Arvi, or Ghuiyan, is one of the most important, popular, and oldest cultivated crops in India. Nearly all parts of the plant- tubers, leaves, and petioles are used as vegetables. It belongs to the family Araceae. Two main types of Colocasia cultivated in India are commonly known as Arvi and Gandayali, with Arvi primarily grown for vegetable use. This crop is cultivated across India, especially in the Northern and North-Eastern regions, and has a high yield potential. Taro is grown for its corms, leaves, and petioles, although the primary focus is on the corms. It is an herbaceous plant, and its leaves and corms are popular vegetables in states such as Gujarat, Uttar Pradesh, Himachal Pradesh, Punjab, Maharashtra, and parts of South India.

Cultivation of Taro

Importance and Uses: Taro is a nutritious crop whose starchy corms and leaves are used in dishes like poi, chips, porridge, and soups. It provides carbohydrates, antioxidants, vitamins, and minerals that support health and prevent diseases. Taro is also processed into products like flour, vermicelli, and wine. Culturally significant in Pacific and Asian regions, it plays roles in festivals and traditions. Agriculturally, it grows well in both wet and dry conditions, aiding soil conservation and sustainable farming. This crop has more medicinal value and is included in many Ayurvedic preparations. Corms are rich source of starch, protein and vitamins A and B, calcium and phosphorus.

Climate and Soil: Taro is a tropical crop that thrives in warm and humid conditions but is adversely affected by hot, dry weather. It cannot tolerate frost but can grow at high altitudes if the cropping season remains frost-free. Well-distributed annual rainfall of 700-1000 mm is ideal for good tuber yield. Taro grows well in subtropical regions where average temperatures range from 21°C to 27°C and can be cultivated during both summer and rainy seasons. Taro can be cultivated in varied type of soils but it thrives best in sandy loam and loamy soils containing sufficient organic matter. It performs best in fertile, well-drained sandy loam soils with a pH of 5.5-7.0 but can also tolerate heavy soils and temporary water logging.

Improved Varieties

Sree Hira: This elite taro variety is well suited for

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both rainfed upland and irrigated medium and lowland conditions. This variety shows tolerance to leaf blight; a disease commonly affecting traditional local cultivars. It produces 12-16 cormels per plant, each measuring about 14-18 cm in length. It also exhibits good cooking quality with low acridity.

Sree Telia: Sree Telia is a short-duration variety that can be harvested within 120 days after planting. It is suitable for summer cultivation with protective irrigation. Each plant produces 7-9 cormels, and the variety is known for its good cooking quality and low acridity (calcium oxalate content of 12.6 mg/100 g). The average yield is 10-12 tonnes per hectare.

Sree Kiran: First hybrid taro in India with oval corms and good cooking quality.

Muktakeshi: This erect, medium-tillering variety has narrow leaves with green petioles. It bears round corms and cylindrical cormels with light grey skin and white flesh. It is non-acrid, has excellent cooking quality, and is resistant to major pests and diseases. It is suitable for both upland and lowland cultivation during summer and rainy seasons**.** The crop matures in about 150-180 days and gives an average yield of 20 tonnes per hectare.

Sree Pallavi: This tall, erect variety has droopy leaves with green margins and petioles. It produces large conical corms with small, numerous club-shaped cormels. The tubers have brown skin, white flesh, and good cooking quality. It is tolerant to leaf blight and Dasheen mosaic virus, matures in seven months, and yields 16-18 tonnes per hectare.

Sree Rashmi: This erect, tall variety has droopy leaves with straight margins and a green to purplish-green petiole. It produces large cylindrical corms and medium conical cormels with brown skin and white flesh. Field tolerant to dasheen mosaic virus, it has acrid-free edible parts, good cooking quality, and matures in 7 months. The yield is 18 t ha^{-1}, with a potential of 32 t ha^{-1}.

Punjab Arvi-1: Taro variety with large, green, obliquely erect leaves and long, sheathing petioles. The corms are long, medium-thick, and brown with creamy inner flesh. It matures in about 175 days and gives an average yield of 90 quintals per acre.

Cultural practices

Field preparation: Land preparation till fine tilth is very essential. In case of taro one deep ploughing and two cross harrowing followed by planking are sufficient to make the soil loose and friable and to conserve soil moisture.

Sowing and Seed Rate: Healthy, disease-free, and uniformly sized planting materials should be selected and stored in a cool place for at least three months before planting. Approximately 750-1000 kg of medium-sized healthy corms is sufficient for one hectare. Sowing of taro can be done from the first fortnight of February up to May-June, depending on the region. For planting, use side tubers weighing 25-35 g each. About 37,000 side tubers, weighing around 1200 kg, are required to plant one hectare. In the plains, taro is planted during June-July, whereas in hilly and some northern regions, sowing is usually done from February to

March.

Method of Sowing: The corms are sown 6 to 7.5 cm deep by keeping 67.5×15 or 45×20 cm distance between rows.

Manures and Fertilizers: Taro is a nutrient-demanding crop that requires 10-15 tonnes of well-decomposed farmyard manure to be incorporated into the soil before sowing. In addition, apply 40 kg nitrogen, l20 kg phosphorus and 20 kg potassium per acre. Half of the nitrogen and the full doses of phosphorus and potassium should be applied at sowing time, while the remaining half of nitrogen should be top-dressed 35-45 days after sowing during hoeing, weeding, and earthing up operations.

Irrigation: Taro requires consistent irrigation to ensure uniform sprouting. Therefore, the field should be watered immediately after sowing and kept moist until germination is complete. During the summer, irrigation should be carried out at intervals of 5-6 days, while in the rainy season, watering should be done only as needed to maintain adequate soil moisture.

Weed Management: Weeds can be controlled by giving one or two hoeings and earthing up should be done after each hoeing. Light hoeing and earthing up are required at 30-45 days and 60-75 days after planting.

Harvesting and Yield: Taro leaves are ready for harvest 45-60 days after planting and are used as a cooked vegetable. The crop matures within 175-200 days, identified by the yellowing of leaves. Corms from early harvests are soft and ideal for table use but unsuitable for long storage. Adequate soil moisture should be maintained during harvesting for easy lifting of corms using spades or similar tools. The corms are cleaned, and primary corms are separated from secondary ones. The average tuber yield ranges between 250 and 440 quintals per hectare, though frequent leaf harvesting can reduce yield to 60-80 quintals per hectare. The dasheen variety shows higher yield potential compared to the arvi type.

Storage: The secondary corms separated from the primary ones are used as seed material for the next crop. These seed corms should be stored in a cool, dry, and well-ventilated place to prevent rotting and fungal infection. For better preservation, the corms can be stored in shaded pits lined with dry leaves and soil or placed in cold storage at a temperature of 7-10°C with 85-90% relative humidity. Proper curing and careful handling before storage further help in maintaining seed viability and reducing decay.

Plant Protection

Major diseases and their management

Leaf Blight (*Phytophthora colocasiae*): This disease causes small purple to brown water-soaked spots on leaves that enlarge, merge, and cause leaf death.

Control: Use resistant varieties, rotate crops, and plant only healthy material. Spray Dithane M-45 (0.2%) or Bordeaux mixture (1%) for control.

Pythium Rot (*Pythium spp.*): A soil-borne fungus that attacks roots and corms, causingyellowing, wilting, and soft, foul-smelling rot.

Control: Practice crop rotation, use disease-free planting materials, and treat soil and corms with fungicides.

Storage Rot/ Rhizopus Rot (*Sclerotium rolfsii, Rhizopus stolonifer*): Infected corms decay and develop soft, discolored tissues.

Control: Avoid injury during harvest and transport. Before storage, dip corms in Captan or Benlate solution (500 ppm) to prevent rotting.

Major Insect-pests and their management

Aphids (*Pentalonia nigronervosa, Aphis gossypii*): These small insects suck sap from tender parts, causing yellowing and reduced tuber yield.

Control: Spray Phosphamidon or Dimethoate (0.03 %) or Malathion (0.1%). Repeat after 7-10 days if necessary.

Red Spider Mite (*Tetranychus cinnabarinus*): Mites form webs on leaves; severe attack causes drying and leaf fall.

Control: Spray Dicofol (0.05%) at the first sign of infestation.

Thrips (*Caliothrips indicus*): Both nymphs and adults suck leaf sap, leaving silvery specks with black dots.

Control: Spray Dimethoate (0.05%) or Phosphamidon (0.05%).

Leaf Cutting Caterpillar (*Aprius convolvuli, Pericallia ricini*): Caterpillars feed on young leaves, reducing foliage quality.

Control: Spray Carbaryl (0.2%) or Endosulfan (0.05%).

Root Knot Nematode (*Meloidogyne incognita*): It causes galls on roots, yellowing, and wilting; severe cases lead to corm rot.

Control: Grow resistant varieties, rotate crops with non-host species, and fumigate soil with Methyl Bromide.

Sweet Potato: The Natural Super Food for a Healthier Life

Manish Kumar, Manpreet Kour, Sanjay Singh and Satyapal Singh

Sweet potatoes are much more than just a delicious food; they are among the most powerful and nutritious vegetables in the world. For centuries, people around the globe have enjoyed sweet potatoes not only for their taste but also for their rich nutrient content. In recent years, scientists and nutritionists have recognized sweet potatoes as a true “super food” and for good reason.

Nutrient Composition and Health Value of Sweet Potato

Sweet potatoes are root vegetables that come in various colors that isorange, purple, white, and yellow. Each variety has its own unique nutrients and benefits, but all share one important trait: they are incredibly healthy. A 100-gram serving of cooked sweet potato contains roughly 90 calories, 2 grams of protein, 0.1 grams of fat, and 21 grams of carbohydrates. More importantly, it provides abundant vitamin A, vitamin C, potassium, fiber, and antioxidants. Unlike regular potatoes, sweet potatoes have a naturally mild sweetness and a smooth, creamy texture when cooked, making them suitable for all age groups, from children to the elderly.

Rich in Vitamin A and Antioxidants: One key reason sweet potatoes are called a super food is their exceptionally high vitamin A content, which comes from beta-carotene the same compound that gives carrots their orange color. Vitamin A supports good vision, a strong immune system, and healthy skin. A medium-sized orange sweet potato provides over 400% of your daily vitamin A requirement. In addition, sweet potatoes are loaded with antioxidants that protect the body from free radicals, harmful molecules that can damage cells and contribute to aging and diseases like cancer. Research shows that the antioxidants in sweet potatoes, especially in purple varieties, may help reduce inflammation and support brain health.

Anticancer Potential of Sweet Potato: Sweet potatoes have been widely examined for their potential in cancer prevention. They contain bioactive compounds such as anthocyanins and phenolic acids that exhibit anti-inflammatory properties. Since chronic inflammation increases cancer risk, these compounds may help suppress inflammation and lower the likelihood of cancer formation. The leaves of sweet potatoes are especially rich in antioxidants like flavonoids and phenolic compounds, which protect cells from oxidative stress and genetic damage-factors closely linked to cancer initiation. Research also indicates

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that sweet potato leaf extracts can trigger apoptosis (programmed cell death) in cancer cells and inhibit their rapid proliferation, thus limiting tumor growth. Moreover, sweet potato leaves may strengthen immune function by enhancing the body's ability to detect and destroy abnormal or malignant cells. The high dietary fiber content in sweet potatoes aids digestion, promotes bowel regularity, and assists in removing potential carcinogens from the body. Their relatively low glycemic index also helps regulate blood sugar levels, contributing to a reduced risk of cancers such as colorectal, breast, and endometrial cancer.

Healthy Vision: Sweet potatoes are beneficial for maintaining healthy vision. They contain beta-carotene, which the body converts into vitamin A, along with lutein and zeaxanthin that help protect the eyes. These vegetables are also rich in antioxidants and anti-inflammatory compounds and have a low glycemic index, all of which support good eye health. Including sweet potatoes in a balanced diet can promote better vision, but overall eye health also relies on regular eye checkups, protecting the eyes from UV rays, and following a healthy lifestyle. Consult an optometrist or ophthalmologist if you have specific vision concerns.

Control of Blood Sugar Levels: Although sweet potatoes have a naturally sweet taste, they possess a low glycemic index (GI), which means they cause a slower increase in blood sugar levels compared to processed foods such as white bread or sugary snacks. Their high fiber content helps slow digestion; allowing glucose to enter the bloodstream gradually.This steady release of energy helps control appetite and maintains consistent energy levels throughout the day. Because of these qualities, health experts often recommend sweet potatoes as a healthy carbohydrate option for people with diabetes or those trying to manage their weight.

Powerhouse of Fiber and Digestive Health: Sweet potatoes are rich in dietary fiber, which is vital for maintaining a healthy digestive system. Fiber prevents constipation, supports beneficial gut bacteria, and lowers the risk of colon cancer. Cooking sweet potatoes with their skins on boosts their fiber content further. The skin provides essential nutrients that aid digestion and help rid the body of toxins. A diet high in fiber also helps lower cholesterol and supports heart health.

Anti-Microbial Activity: Sweet potatoes possess antimutagenic properties, meaning they can help reduce DNA mutations that may lead to cancer. They are abundant in dietary fiber, antioxidants, phytochemicals, and anthocyanins, all of which contribute to their antimutagenic effects. Moreover, sweet potatoes can enhance the activity of detoxification enzymes in the body and exhibit anti-inflammatory actions that help inhibit tumor growth and decrease mutagenesis. Cooking methods such as boiling and steaming are more effective at preserving the antioxidant and antimutagenic potential of sweet potatoes compared to frying or baking.

Boosts Immunity and Reduces Inflammation: The colorful compounds in sweet potatoes especially beta-carotene and anthocyanins (found in purple sweet potatoes) have strong anti-inflammatory effects. These natural chemicals help fight infections and decrease inflammation linked to conditions like arthritis, asthma, and heart disease.Vitamin C in sweet potatoes also enhances the immune system by stimulating the production of white blood cells that combat infections. Including sweet potatoes regularly in your diet can strengthen your defenses against common illnesses such as colds and flu.

Lowers the Risk of Obesity: Sweet potatoes can be a valuable part of a healthy weight management plan. They are high in dietary fiber, low in calories, and provide slow-digesting carbohydrates. In addition, they supply essential vitamins and minerals that support overall health. Research indicates that eating whole, unprocessed foods like sweet potatoes may help lower the risk of overeating. It is important to pair sweet potatoes with other nutrient-dense foods and maintain regular physical activity to achieve and sustain a healthy weight. For personalized advice on nutrient needs and dietary restrictions, it is best to consult a healthcare professional or registered dietitian.

Supports Heart and Brain Health: Sweet potatoes are an excellent source of potassium, which helps maintain healthy blood pressure and fluid balance in the body. Potassium works by counteracting the effects of sodium and relaxing the walls of blood vessels, thereby lowering the risk of hypertension and stroke. In addition to these benefits, the anti-oxidants in sweet potatoes protect brain cells from damage and may help slow down age-related cognitive decline. Research also indicates that anthocyanins found in purple sweet potatoes can enhance memory and reduce oxidative stress in the brain, contributing to overall brain health.

Promotes Healthy Digestion: Sweet potatoes are an excellent food choice for promoting healthy digestion, as they contain several components that contribute to improved digestive health. They are rich in dietary fiber, which adds bulk to stool, supports regular bowel movements, and nourishes beneficial gut bacteria. Their high water content helps prevent dehydration and maintains proper digestive function. Sweet potatoes also contain natural enzymes that aid in breaking down and digesting carbohydrates, improving nutrient absorption. Furthermore, their antioxidants and anti-inflammatory properties help reduce inflammation in the digestive tract and promote overall digestive wellness. As a good source of vitamin B6, sweet potatoes also assist in the production of digestive enzymes necessary for efficient digestion.

Easy to Cook and Delicious to Eat: Sweet potatoes are loved worldwide for their versatility in cooking. They can be baked, boiled, mashed, roasted, or steamed, making them ideal for a variety of dishes, from snacks to desserts. You can enjoy them as baked sweet potatoes topped with butter or olive oil, crispy fries seasoned with salt and pepper, or mashed with milk and honey for a smooth, rich flavor. Another healthy option is sweet potato soup, made by blending boiled sweet potatoes with onion, garlic, and vegetable broth. These delicious dishes not only satisfy cravings but also keep you full longer, helping to prevent unhealthy snacking.

Environmental and Economic Benefits: Sweet potatoes are easy to grow and require less fertilizer and water compared to many other crops. Farmers across Asia, Africa, and the Americas rely on them as a staple food. They thrive even in poor soil and dry conditions, making them vital for food security. The Food and Agriculture Organization (FAO) recognizes sweet potatoes as a climate-smart crop for their resilience and nutritional value. They are a sustainable food choice that benefits both people and the planet.

Conclusion

Sweet potatoes are safe and nutritious for almost everyone. They are particularly beneficial for children, as they support healthy growth and strengthen the immune system. Elderly individuals can also benefit from sweet potatoes because they promote better digestion and support heart health. Athletes often include them in their diets since they provide steady, long-lasting energy and help with muscle recovery after exercise. Additionally, people with diabetes can enjoy sweet potatoes due to their low glycemic index, which helps regulate blood sugar levels effectively. Sweet potatoes truly earn their title as a super food. They are natural, affordable, and packed with nutrients that benefit almost every part of the body from the eyes and skin to the heart and brain. Adding sweet potatoes to your diet is one of the easiest ways to boost your overall health while enjoying a nutritious and versatile food.

Production Technology of Broccoli

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Broccoli (*Brassica oleracea var. italica*) is a nutritious cool season vegetable rich in vitamins, minerals, and anticancer compounds. In India, it grows mainly in Himachal Pradesh, Uttarakhand, Gujarat, Maharashtra, Punjab, Haryana, Uttar Pradesh, and Rajasthan. These states offer favorable climates and soils for broccoli cultivation, primarily in the *rabi* season. It is of two main types: sprouting and heading. Sprouting broccoli produces multiple smaller flower heads from axillary shoots after removing the main head, while heading varieties form a single large head similar to cauliflower, which can vary in color from green to purple or white.

Importance and uses

Broccoli is valued in India and worldwide for its high nutritional content and anticancer properties. It contains significantly more vitamin A than cauliflower and cabbage, along with vitamins C, minerals, proteins and compounds like sulphoraphane and carotenoids that help reduce cancer risk. In addition broccoli contains 103 mg calcium, 78 mg phosphorus, 382 mg potassium, and 113 mg vitamin C per 100 g edible portion. It also includes beneficial sulfur-containing secondary metabolites called glucosinolates, which contribute to its health promoting properties It also may lower cholesterol levels. Broccoli is marketed fresh, frozen, and used in salads.

Climate and Soil: Broccoli is a cool season crop that can tolerate mild frost and grows best in temperate to subtropical climates. Optimal vegetative growth occurs at 20-25°C, while 15-20°C favors head formation. Higher temperatures cause heads to loosen. It requires well-drained, fertile soils with a pH between 5 to 6.5. Light sandy loam to silt loam soils rich in organic matter are suitable for broccoli cultivation. Dry soil makes shoots fibrous, and temperature below optimum during growing time delays maturity and small sprouts may be formed.

Improved Varieties

The varieties are classified into two main groups sprouting and heading types:

Palam Haritika: This variety has dark green, upright leaves with a long stem that bears a terminal head. The heads are dark green and ready for harvest in about 150 days. It is resistant to yellow eyes and dry buds, with a yield potential of 20-25 tonnes per hectare.

Palam Samridhi: This is the first indigenous, high-yielding green sprouting broccoli variety. It develops a large terminal head weighing 400-500 g and is

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ready for harvest in about 85-90 days. Suitable for sowing in September-October and transplanting in October-November in northern plains, it is free from yellow eye and bracketing defects. The average yield is around 15-20 tonnes per hectare.

Pusa KTS-1: A medium-tall variety (65-70 cm) with waxy, dark green foliage and slightly wavy leaf margins. The heads are compact, solid green with small, slightly raised beads at the center. The main head measures 6-15 cm across and weighs 350-450 g. It matures in 90-105 days after transplanting in temperate regions, and 5-10 days earlier in tropical plains.

Punjab Broccoli-1: It has smooth and wavy dark green leaves with a subtle bluish hue. Both its primary and secondary sprouts are dark green, dense, visually appealing, and juicy. The primary sprouts reach maturity around 65 days following transplanting. This variety is versatile, suitable for consumption both raw in salads and cooked dishes. Its typical yield is 150-175 quintals per hectare.

Palam Kanchan: It is a heading type broccoli characterized by its yellowish-green color and large-sized plants with long, upright green leaves. It forms compact heads that are yellowish-green and requires about 150 days to reach harvest maturity, yielding approximately 25-27 tonnes per hectare.

Palam Vichitra: It is a purple heading variety with medium-sized plants exhibiting a purple tinge throughout. Its heads are tight and richly purple, known for being a good source of antioxidants. This variety produces an average yield of 20-25 t ha^{-1}.

Nursery Raising and Seed rate

Nursery beds should be well prepared and mixed with 5 kg of sieved farmyard manure. Avoid using excess nitrogen. The ideal time for sowing broccoli seeds in the nursery is from mid-August to mid-September in the north Indian plains. Two days before sowing, drench the nursery beds with a 0.3% Captan or Thiram solution at 5 litres per square meter to control damping-off pathogens such as Pythium, Rhizoctonia, Phytophthora, and Fusarium. Seedlings are transplanted into the field when they are about 30-35 days old or at 4-5 leaves stage. Seed rate of 500-650 g is sufficient for one hectare. Sow seeds in rows 8-10 cm apart at a depth of 1.5-2.5 cm. To produce seedlings for one hectare of crop, about 60-80 square meters of nursery area is needed. To avoid bolting and buttoning, sow the crop at the right time. Transplant seedlings into well-prepared pits, called and irrigate immediately after transplanting.

Field Preparation and Transplanting of Seedlings

: Field preparation for broccoli involves deep ploughing and thorough leveling of well-drained, fertile soil. Incorporate 25-40 tons of well-rotted farmyard manure or compost per hectare. Create fine soil tilth by harrowing. Seedlings are ready for transplanting about 30 to 40 days after sowing. Using over aged seedlings results in weak plant growth and the formation of small heads. In the northern plains of India, transplanting is usually done from mid-September to mid-October, while in hilly areas it takes place from late August to September. The spacing between plants depends on the growing season, variety, and harvesting method, and typically ranges from 40 × 30 cm to 60 × 45 cm. Transplant seedlings into well-prepared pits, called and irrigate immediately after transplanting.

Nutrient Management: For better yield and healthy crop, apply 125 kg of nitrogen, 62 kg of phosphorus (P_2O_5), and 62 kg of potassium (K_2O). Incorporate these fertilizes into the soil before transplanting, along with half of the nitrogen dose. Apply the other half of nitrogen as a top dressing one month after transplanting. Like cauliflower, this crop is sensitive to deficiencies of micronutrients such as molybdenum and boron. To prevent these deficiencies, apply 500 g of molybdenum and 10-15 kg of borax per hectare.

Irrigation: The crop grows well under high moisture conditions. If grown in soils having longer water-retaining capacity, it gives optimum yield. Dry spells during early growth and head development stage reduce the yield considerably. First irrigation should be given just after transplanting. Subsequent irrigations can be given at an interval of 8-10 days depending upon soil type and weather. The total number of irrigations required is 8-12, to get good harvest.

Weed Management: During transplanting, favorable weather also promotes weed growth. To control weeds, apply weedicides such as Fluchloralin (0.5 kg ha^{-1}), Nitrofen (2 kg ha^{-1}), and Alachlor (0.2 kg ha^{-1}) two to three days before transplanting. Regular intercultural operations should be carried out to keep the field weed-free and improve root aeration, but deep hoeing must be avoided to prevent root injury.

Harvesting and Yield

Early varieties mature in 40-50 days, mid-season types in 60-100 days, and late varieties take over 100 days after transplanting. In the plains, the crop is generally harvested from December to March, while in the northern hills of India, harvesting occurs from November to April. The heads should be harvested as soon as they reach the right size, as delays can cause the buds to open and the heads to loosen, reducing market quality. The central head is cut along with about 15 cm of the thick stem. Yield varies with the variety, ranging from 6 to 14 tonnes per hectare.

Insect-Pests Management

Cabbage butterfly (*Pieris brassicae*): Its larvae feed on leaves from the edges inward, leaving only the main veins. They also cause heavy losses in seed crops.

Diamondback moth (*Plutella xylostella*): The larvae attack the leaves around the head and the growing heart, often damaging the growing tips as well.

Aphids (*Brevicoryne brassicae* and *Myzus persicae*): These pests cause serious harm to seedlings, curd formation, and seed setting stages by sucking sap from leaves, stems, flowers, and pods of the crop.

Control: Apply 0.20% Malathion at intervals of 10-15 days to control cabbage butterfly, diamondback moth, tobacco caterpillar, and aphids whenever infestation appears. Once heads or flower buds begin to form saprout, use a 0.1% Pyrethrins spray in place of Malathion.

Disease Management:

Damping off (*Pythium spp*.): A fungal disease affecting seedlings in nurseries. It attacks the stem base near the soil, causing water-soaked rotting, collapse, and death of seedlings.

Control: Drench nursery beds 15 days before sowing with 25-30 ml Formaldehyde per litre of water or Captan 2-3 g $litre^{-1}$. Repeat Captan drenching after germination and treat seeds with Captan 35 at 2 g kg^{-1} before sowing.

Black rot (*Xanthomonas campestris pv. campestris*): It infects leaves through pores or insect wounds, causing yellow V-shaped lesions with black veins.

Control: Hot water seed treatment at 50±2°C for 30 min. followed by 100 ppm Streptocycline dip or use Streptocycline or Aureomycin (0.01%) sprays.

Downy mildew (*Peronospora parasitica*): It produces purplish-brown spots on leaf undersides. The disease severely affects the crop at all stages of growth.

Control: Spray Ridomil MZ 72 (0.5 g $litre^{-1}$) or Dithane M-45 (1.5-2 g $litre^{-1}$) every 10-15 days.

Production Technology of Garlic

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Garlic (*Allium sativum* L.) is a popular bulbous vegetable and spice crop grown across India for its unique flavor and health-promoting properties. It belongs to the family Amaryllidaceae. It is valued for its pungent bulbs containing bioactive compounds, especially allicin. Native to Central Asia, garlic thrives well in cool climates and is a staple in Indian cuisine and traditional medicine. In India, major garlic producing states include Madhya Pradesh, Rajasthan, and Uttar Pradesh, which together account for about 85% of the country's total garlic production. Other notable states are Gujarat, Punjab, Haryana, and West Bengal, each contributing smaller shares to the overall output.

Importance and uses

Garlic is used as a spice and condiment throughout India. It has a higher nutritive value than other bulb crops. Garlic's importance lies in both its culinary and therapeutic uses. It enriches food with unique taste and aroma while offering health benefits due to its sulfur-containing compounds like allicin, which have antimicrobial, antioxidant, and anti-inflammatory effects. Medicinally, garlic is known to help reduce blood pressure and cholesterol, boost the immune system, improve cardiovascular health, and support liver function. It also exhibits antibacterial, antiviral, and antifungal properties that help fight infections. Additionally, garlic has been traditionally used to treat infections, respiratory problems, skin conditions, and inflammation. Its broad therapeutic uses make it an essential herb for both health and cuisine. Garlic contains 0.1-0.4% essential oil, with diallyl disulfide being responsible for the true garlic odor. Fresh garlic bulbs and whole plants yield 0.1-0.2% and 0.05-0.9% essential oils, respectively, when steam distilled and up to 0.5% oil can be extracted from the bulbs.

Improved Verities

Agrifound White (G-41): The variety has compact silvery white bulbs (3.5-4.5 cm) with 20-25 cloves. It suits *rabi* season free of purple blotch and stemphylium blight, has 41% TSS, 42-43% dry matter, good storage, and yields 13 tonnes ha^{-1}.

Yamuna Safed (G-1): It has compact, silvery white bulbs (4-4.5 cm) with 24-30 sickle-shaped cloves and creamy flesh. It tolerates thrips, purple blotch, and stemphylium blight. With 38% TSS, 39.5% dry matter, and a yield of 15-18 tonnes ha^{-1}, it is suitable for cultivation across India.

G-50: The variety has compact, attractive bulbs with

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36-40 white-creamy cloves, 3.5-4 cm diameter, 38-40% TSS, and 40-42% dry matter, yielding 16-20 tonnes ha^{-1}, suitable for northern India.

G-282: The variety has wider leaves, large creamy white bulbs (5-6 cm) with 15-16 cloves, 38-42% TSS, 39-43% dry matter, moderate storage, yields 17-20 tonnes ha^{-1} and performs well in northern and central India, suitable for export.

Agrifound Parvati (G-313): This long day garlic variety suits northern hill regions. Its large creamy white bulbs with a pink tinge (5-6 cm) have 10-16 cloves and good disease tolerance. It yields 17.5-22.5 tonnes ha^{-1}, stores moderately well, and is export suitable.

HG-17: This high-yield garlic variety thrives in Haryana's conditions. Its white, compact bulbs weigh 25-30 g and have 28-32 cloves. Moderately resistant to pink root disease, it matures in 160-170 days and yields about 120-150 quintals per hectare.

PG-18: The plants are soft-necked and non-bolting with green leaves. Bulbs are large (4.55 cm), white, and weigh about 28.4 g, containing around 26 medium to large cloves. They have 38% dry matter, 1.15% allicin, and yield about 130-150 q ha^{-1}.

Climate and Soil

Garlic is a frost-hardy crop that grows best in cool, moist conditions followed by a dry period (25°C-30°C) for bulb maturity. Two types exist: long-day and short-day varieties, with short-day types common in India. Early planting encourages better vegetative growth under cool, short-day conditions. The critical day length for bulbing is around 12 hours, and pre-exposure of cloves to about 20°C for 1-2 months promotes bulbing. Garlic thrives in fertile, well-drained loamy soil with a pH of 6-7, while alkaline and saline soils are unsuitable.

Field Preparation and Sowing Time: The field is ploughed 4-5 times to get a fine tilth, with shallow ploughing of 8-10 cm depth. After levelling with planking, plots are made wide enough for manual intercultural work. Sowing is best done from the last week of September to the first week of October in northern plains mainly.

Propagation and Seed Rate: Garlic is mainly propagated vegetatively using cloves, though some varieties also produce bulbils that can serve as planting material. Tissue culture techniques have been developed to raise disease-free plants. For planting, select healthy cloves larger than 8-10 mm from the outer bulb layers to achieve higher yield and better quality bulbs. Small, central cloves should be avoided. Approximately 225-250 kg of cloves are required per acre, or about 500-600 kg per hectare.

Methods of Planting: Garlic is planted using three main methods: dibbling, furrow planting and broadcasting. In the dibbling method, the field is divided into small plots, and cloves are planted 5-7.5 cm deep with their tips facing upward. In furrow planting, furrows are prepared with a hand hoe; cloves are placed by hand, and then lightly covered with soil. In the broadcasting method, cloves are evenly scattered over a leveled field, covered by harrowing, and the field is divided into plots for irrigation. Close spacing of 15 cm between rows and

7.5 cm between plants within a row has been found most suitable for better growth and yield. For bigger bulb and bigger cloves a spacing of 15×10 cm is recommended.

Manures and Fertilizers: Incorporate about 30-50 tonnes of farmyard manure or compost per hectare into the soil 20-30 days before sowing to enrich soil fertility. Along with organic manure, apply fertilizers containing 125 kg N, 62.5 kg P_2O_5, 60 kg K_2O, and 30 kg sulfur. Apply the entire phosphorus dose as a basal application before planting, while nitrogen should be applied in three equal splits at 30, 45 and 60 days after sowing in northern plains. The use of micronutrients also helps enhance yield; foliar sprays of $MnSO_4$ (0.1%), boric acid (0.2%), $CuSO_4$ (0.02%), or $ZnSO_4$ (0.02%) promote dry matter accumulation in cloves. Applying borax up to 10 kg per hectare further improves bulb size and overall yield.

Irrigation: Irrigate the field immediately after planting, then every 10-15 days depending on soil and weather. Around 10-12 irrigations are needed. Avoid excess moisture at maturity to prevent leaf regrowth and sprouting, which lowers storage quality.

Weed management: Garlic has shallow roots, so weeds should be controlled by 2-3 shallow hoeing or by applying 62.5 quintals of paddy straw per hectare as mulch after sowing. For chemical control, use Fluchloralin 1 kg (Basalin 45% - 2.25 L) per hectare before sowing or Pendimethalin 1-1.25 kg (Stomp 30% - 3.25-4.25 L) ha^{-1} 8-10 days after sowing.

Harvesting and Yield: The crop is ready for harvest when the leaves turn yellowish-brown, start drying, and bend down. Bulb maturity occurs about 4-5 months after planting, depending on the soil and season. Harvesting is done manually by pulling out plants with their tops. The harvested plants are arranged in windrows, combining several rows together for proper drying. In northern pockets garlic is harvested during March-April. The average yield is 12-20 tonnes ha^{-1} depending upon the variety.

Curing and Storage: Curing is done to remove excess moisture and help bulbs become firm and dormant. After harvest, bulbs are cured in the field for about a week, then in shade for 7-8 days with tops intact or trimmed to 2.5 cm. Shade curing can be done on ventilated floors or wire racks. Well-cured bulbs store safely for 6-8 months, but humidity above 70% may cause mold or sprouting. Cold storage at 0-2.2°C with 60-70% humidity improves shelf life.

Diseases and Insect-Pests

Purple blotch (*Alternaria porri*): The fungus causes purple spots on leaves and the seed stalks. It also infects the inflorescence and seed.

Control: Use disease-free seed for sowing. When the first symptoms of the disease appear, spray the crop with 750 g of Caviet 25 WG or 1.5 kg of Indofil M-45 along with 500 ml of Triton or linseed oil (as a sticker) in 500 litres of water per hectare. Repeat the spray three or more times at 10-days interval for effective disease control.

Onion thrips (*Thrips tabaci*): Minute pale-colored insects feed on the foliage from February to May, causing whitish spots that later lead to leaf curling-a condition known as “silvertop.” This pest becomes particularly harmful during the flowering stage, as it severely affects seed formation and reduces overall seed yield

Control: Spray 60 g Jump 80 WG (fipronil) or 650 ml Rogor 30 EC (dimethoate) in 250 litres of water per hectare.

Scientific Cultivation of Coloured Capsicum

Utkarsh Singh and Ankush Chaudhary

Abstract

Coloured capsicum (sweet bell pepper; *Capsicum annuum* L.) is a high-value vegetable crop valued for its nutritional quality (vitamins, carotenoids), visual appeal and strong market demand. Scientific cultivation of coloured capsicum integrates choice of cultivar, propagation, protected/field culture, precise climate and soil management, fertigation and irrigation, integrated pest and disease management (IPDM), and post-harvest handling to maximize yield, fruit quality and shelf-life. This review synthesizes current practical and physiological knowledge relevant to growers and researchers, covering genotype × environment interactions for color and quality, nursery practices, transplanting, spacing and trellising, nutrient and water management (with emphasis on fertigation/drip in protected culture), common pests and diseases and their integrated control, postharvest physiology (including optimal cooling and storage to avoid chilling injury), and research priorities to further improve colored-capsicum production systems. Key evidence and technical recommendations are referenced to primary and authoritative sources.

Introduction

Coloured capsicum (green, red, yellow, orange, purple cultivars) is produced for fresh markets, processing and specialty segments. The red/ yellow/ orange color classes are driven by accumulation of carotenoids (e.g., capsanthin, capsorubin, β-carotene) during ripening, which also determine antioxidant capacity and nutritional value. Demand for coloured fruits often commands premium prices, especially when produced off-season or under protected cultivation. Understanding physiological drivers of color development, together with optimized agronomy and postharvest practice, is essential to deliver both high yield and consistent colour/quality (Mateos *et al.*, 2013).

Botany and major cultivated types

Capsicum annuum L. is the primary species used for sweet coloured peppers. Fruit morphology ranges from blocky bell types to tapered long types; breeders have introduced many coloured varieties that mature from green to stable red/yellow/ orange/purple at harvest. Cultivars differ in days-to-harvest, yield potential, susceptibility to disorders and postharvest behaviour; cultivar choice must therefore match the intended market (green vs fully-coloured harvest), production system (open field vs greenhouse) and climatic region (Mateos *et al.*, 2013).

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Environment: optimum climate and protected cultivation

Capsicum is a warm-season crop: optimum day temperatures are typically in the low to mid-20s °C (≈20-30°C) and cooler nights (≈15-20°C) favour flower retention and fruit set; extreme heat (>30-35°C) or cool nights (<12-15°C) reduce fruit set and quality (O'Donoghue *et al.,* 2018). In protected cultivation (polyhouse/ greenhouse) growers maintain temperatures, relative humidity and light to favour fruit set and colour development; fertigation with drip systems plus climate control substantially increases off-season yields and returns. Practical protected-culture targets reported in production guides and government recommendations include day temperatures ~25-30°C and relative humidity 50-70% (with ventilation to avoid excessive humidity).

Soil and site selection

Soil type and drainage: Ideal soils are well-drained loams with good organic matter; waterlogging must be avoided to reduce root-rot and N loss.

Soil pH: Optimal pH is generally 5.5-6.8; liming should be applied to reach this range if soils are acidic.

Previous cropping: Avoid planting where Solanaceae pathogens (e.g., *Phytophthora*, *Verticillium*, *Fusarium*) have been severe in previous crops; use rotations of 2-3 years where possible.

Propagation and nursery management

Seed quality: Use certified seed of known genetic background. For coloured types, hybrid seed is common for uniform fruit shape and color.

Sowing and substrate: Sow in trays or plug cells in well-drained seed-mix. Warm germination (soil temp ~25-30°C) speeds emergence; germination declines markedly below ~15°C.

Seedling age at transplant: Transplant robust 6–8-week-old seedlings (3-5 true leaves) to field or protected beds; avoid root-bound seedlings to encourage establishment.

Hardening off: Gradually reduce humidity and increase light 7-10 days before transplanting; this reduces transplant shock and improves survival.

Planting, spacing and training

Proper planting geometry, spacing and training are fundamental components in the scientific cultivation of coloured capsicum, as they profoundly influence plant growth, microclimate within the canopy, pest and disease dynamics, and ultimately, yield and fruit quality. The choice of spacing primarily depends on factors such as cultivar growth habit, production system (open field or protected cultivation), trellising method, and desired market size of fruits. In protected cultivation, where environmental conditions are controlled and vertical growth can be supported, a spacing of 45-60 cm between plants within a row and 60-90 cm between rows is generally recommended. This arrangement optimizes light interception, air circulation, and access for maintenance operations such as pruning and harvesting. Under high-density planting systems in greenhouses, double-row beds are often used to maximize space efficiency without compromising plant health (Cantwell, 1996). Adequate spacing is crucial to minimize canopy congestion, which can otherwise increase relative humidity, create microclimates conducive to fungal and bacterial diseases, and hinder effective pollination and fruit set. Conversely, overly wide spacing can lead to underutilization of available growing area, reducing total yield per unit area. Hence, spacing must strike a balance between maximizing yield potential and maintaining plant health and ease of management.

The planting depth and support system are equally critical in determining plant stability and productivity. Transplants should be set at the same depth as they were in the nursery to prevent stem rot and ensure proper root establishment. Deep planting can cause collar rot and stunted growth, while shallow planting exposes roots to temperature fluctuations. In high-density greenhouse cultivation, the adoption of a single-stem or two-stem training system using vertical trellis or nylon string support has become standard practice. Each plant is gently tied to a vertical string anchored to overhead wires or trellis frames, allowing the stem to grow upright. This method facilitates efficient canopy management by preventing branch overcrowding and promoting uniform exposure of leaves and fruits to sunlight, which enhances photosynthetic efficiency and pigment development in coloured fruits. Regular pruning and removal of side shoots or suckers are performed to maintain the desired canopy structure, improve air circulation, and redirect assimilates towards fruit growth. The trellising system also reduces fruit contact with the soil, minimizing the incidence of fruit rot and mechanical injury, thereby improving marketable yield and fruit quality (Mateos *et al.*, 2013).

Mulching forms an integral part of modern capsicum cultivation and is widely practiced in both open-field and protected systems. The use of plastic mulches, particularly black or silver-black poly-ethylene sheets, provides multiple agronomic benefits. Mulching suppresses weed emergence, conserves soil moisture by reducing evaporation, and moderates soil temperature, which is particularly advantageous during early crop establishment and winter cultivation. The reflective properties of white or silver mulches also help repel insect pests such as aphids and thrips, which are vectors of viral diseases (Cantwell, 1996). In open-field conditions, mulching significantly improves water-use efficiency and enhances the uniformity of soil moisture around the root zone, thereby reducing physiological disorders like blossom end rot. Alternatively, in low-input or organic systems, organic mulches such as straw, grass clippings, or composted crop residues can be used to achieve similar effects while contributing to soil organic matter enrichment and microbial activity. Regardless of the material used, mulching complements the drip irrigation system commonly employed in coloured capsicum production by maintaining consistent soil moisture and temperature factors essential for optimum root function and fruit development (O'Donoghue *et al.,* 2018).

In conclusion, scientific management of plant

-ing geometry, trellising, and mulching serves as the foundation for high-quality coloured capsicum production. Well-planned spacing ensures healthy canopy structure and minimizes disease pressure; efficient trellising enhances light use and facilitates maintenance; and judicious mulching improves soil health and water conservation. Together, these practices not only enhance fruit quality and colour development but also contribute to sustainable and economically viable production systems in both open and protected environments.

Irrigation and water management

Drip irrigation and fertigation: Drip systems provide precise, localized water and nutrient delivery, reduce foliar wetting (disease suppression) and are widely recommended for capsicum, especially in protected culture. Pulse/frequent shallow irrigations during fruit growth stabilize calcium uptake and reduce blossom end rot.

Irrigation scheduling: Schedule on crop evapo-transpiration (ETc) or substrate moisture tension sensors; avoid prolonged drought stress (reduces set) and waterlogging (root disease).

Nutrition and fertiliser management

General principles: Avoid excessive nitrogen during fruiting (promotes vegetative growth at the expense of fruit set); increase phosphorus (P) and potassium (K) ratios after flowering to enhance fruit development and quality. Foliar sprays of calcium can reduce blossom-end rot when applied appropriately.

Fertigation: In protected cultivation, fertigation allows split applications and real-time adjustments; frequent small N doses with K and Ca supplementation during fruit fill are common. Soil and tissue testing should guide rates.

Canopy management and pruning

Pruning and sucker removal: For single-stem trellis systems, remove lower leaves and non-productive shoots to enhance light penetration and air flow. Pruning timing influences fruit count and size; excessive pruning reduces total yield.

Pollination: Many capsicum cultivars are self-pollinating; greenhouse growers may introduce bumblebees or use manual vibration to improve fruit set under low wind conditions.

Pest and disease management (integrated approach)

Major insect pests: Aphids, thrips, whiteflies, cutworms and fruit-borers are important in many regions. In protected culture, whitefly and thrips management is critical because they also vector viruses.

Major diseases: Bacterial spot, *Phytophthora* blight, *Alternaria*/ *Botrytis* rots, viruses (e.g., CMV, ToMV), and fungal wilts can cause major losses. Use resistant varieties where available, sanitation, good drainage, crop rotation, clean transplants, and well-timed chemical/biological controls as part of IPM. Avoid overhead irrigation to reduce foliar disease.

Biological control and cultural tactics: Use of natural enemies, reflective mulches for thrips/ whitefly suppression in some systems, and conservation biological control in open field are increasingly integrated into management programs.

Physiological disorders

Blossom end rot (BER): Linked to inconsistent water supply and localized Ca deficiency; prevention includes regular irrigation, calcium foliar sprays and avoiding excessive N. UC Davis and other extension authorities emphasize water and calcium management to minimize BER.

Chilling injury: Green fruit are more chilling-sensitive; storage below ~7°C can cause pitting and internal disorders. For maximum shelf life, recommended storage temperatures for capsicum are around 7-10°C, with high relative humidity (>90%) coloured (ripe) peppers are somewhat less chilling sensitive than green ones. Rapid cooling after harvest reduces weight loss and decay.

Harvesting for colour and quality

The harvesting stage plays a pivotal role in determining both the visual appeal and market value of coloured capsicum, as fruit maturity directly influences its pigment development, nutritional content, and shelf life. For green capsicum, the primary maturity indicators include the attainment of full fruit size, firm texture, and a uniform dark-green colour. Harvesting at this physiological but not fully ripened stage ensures extended storage life and firm fruit for transport. In contrast, coloured capsicum (red, yellow, orange, or purple types) is harvested at or near full physiological maturity, when the fruits exhibit a minimum of 50% to full surface coloration depending on market preferences and supply chain requirements. The transition from green to the desired hue results from chlorophyll degradation and the accumulation of carotenoids such as capsanthin, capsorubin, and β-carotene, which are responsible for the distinctive colour intensity and enhanced antioxidant properties of mature fruits. Generally, coloured bell peppers require 60-90 days after transplanting to reach harvest maturity, although the duration may vary with cultivar, climatic conditions, and growing system (open field or protected). Timely harvesting is essential to avoid over-maturity, which can lead to fruit softening, shrivelling, and susceptibility to microbial decay (O'Donoghue *et al.*, 2018). The harvesting operation should be performed with utmost care, preferably during cooler hours of the day, using sharp pruning shears or knives to detach fruits without damaging the stems or peduncles, as bruising or tearing of the fruit surface significantly increases the risk of postharvest rot. Additionally, harvested fruits should be immediately placed in shaded, ventilated containers and transported to the packing area for grading and cooling. Gentle handling throughout the process preserves firmness, glossiness and the appealing colour that determine consumer acceptance and market premium, ensuring both quality retention and economic profitability for growers.

Postharvest physiology and handling

Respiration and ethylene: Capsicums are generally non-climacteric and produce very low ethylene; colour development is not strongly ethylene-driven in sweet peppers. Holding partially coloured fruit at warm temperatures (20-25°C) and high humidity can accelerate color change if needed before marketing.

Storage recommendations: Rapid precooling and storage at recommended temperatures (~7-10°C) with high humidity optimizes shelf life (weeks rather than days) while avoiding chilling injury. Modified atmosphere packaging and forced-air cooling are important technologies used to extend shelf life and retain colour and firmness. Recent reviews detail modern approaches to reduce postharvest losses in bell pepper supply chains.

Quality traits: pigments, antioxidants and nutrition

Colour biochemistry: Colour change during ripening is a switch from chlorophyll dominance (green) to carotenoid accumulation (yellow/red/ orange pigments). Major carotenoids (capsanthin, capsorubin, β-carotene, lutein) determine hue and nutritional β-carotene content. Management of pre-harvest environment (light, temperature) influences carotenoid biosynthesis and final colour intensity.

Antioxidant systems: The antioxidant profile (vitamin C, phenolics, carotenoids) is influenced by cultivar and environment; temperature stresses and postharvest storage can modulate antioxidant enzyme activities and thus affect quality retention.

Protected cultivation economics and sustain-ability

Protected cultivation (polyhouse/ green-house) enables off-season production, better climate control, higher yields and superior fruit quality, but with higher capital and operating costs. Accurate fertigation, integrated pest management, and energy-efficient climate control are key to economic sustainability. Case studies and extension resources highlight profitability when management is optimized and markets accessed appropriately (O'Donoghue *et al.*, 2018).

Research needs and future directions

Future research on coloured capsicum cultivation should focus on a holistic integration of genetics, physiology, agronomy, and technology to enhance both productivity and sustainability. Genotype × environment (G×E) interaction studies are crucial to identify and develop cultivars that maintain superior fruit colour intensity, high yield, and resilience under varying agro-climatic conditions, particularly in regions facing climate variability. Advances in molecular breeding and functional genomics should be leveraged to enhance carotenoid biosynthetic pathways for richer pigmentation and improved antioxidant profiles, while simultaneously incorporating genes for resistance against major pathogens such as *Phytophthora capsici* and viral complexes. In the realm of agronomic management, precision fertigation and sensor-assisted irrigation systems hold promise for optimizing nutrient and water delivery, thereby minimizing physiological disorders such as blossom end rot and improving overall fruit uniformity and quality. Translational research is also required to adapt postharvest technologies including low-cost evaporative cooling systems, modified atmosphere packaging (MAP), and biopolymer-based coatings for small and medium-scale growers to reduce postharvest losses and extend shelf life. Furthermore, the development of sustainable protected cultivation systems with reduced carbon and energy footprints through passive climate control, thermal screens, and solar-assisted greenhouse designs will be instrumental in mitigating production costs and environmental impacts. Integration of biological control agents and eco-friendly pest management strategies within these systems will further ensure long-term sustainability and food safety. Collectively, these research directions will underpin the future of coloured capsicum cultivation, ensuring it remains profitable, climate-resilient, and aligned with the principles of sustainable and precision horticulture (O'Donoghue *et al.*, 2018).

Conclusions

Scientific cultivation of coloured capsicum merges physiological knowledge (temperature, light, pigment biosynthesis), precise agronomy (nursery, spacing, fertigation), pest/disease IPM, and modern postharvest practices (rapid cooling, appropriate storage) to produce fruits with attractive colour, high nutritional value and longer shelf life. Protected cultivation, when economically feasible, offers clear advantages for off-season, high-value coloured capsicum. Continued research in cultivar development, precision nutrient/water management and affordable postharvest technologies will further improve the sustainability and profitability of coloured capsicum production.

References

Mateos, R. M., Jiménez, A., Román, P., Romojaro, F., Bacarizo, S., Leterrier, M., Gómez, M., Sevilla, F., Del Río, L. A., Corpas, F. J. and Palma, J. M. (2013). Antioxidant systems from pepper (*Capsicum annuum* L.): involvement in the response to temperature changes in ripe fruits. *International Journal of Molecular Sciences*, 14(5): 9556-9580.

O'Donoghue, E. M., Brummell, D. A., McKenzie, M. J., Hunter, D. A. and Lill, R. E. (2018). Sweet capsicum: postharvest physiology and technologies. *New Zealand Journal of Crop and Horticultural Science*, 46(4): 269-297.

Cantwell, M. (1996). Bell Pepper (produce fact sheet). Postharvest Research and Extension Center, University of California, Davis.

Role of Strigolactones in Seed Germination and Seedling Development

Hemanthkumar Y. G. and Chandana B.

Introduction

Plant hormones are small molecules that regulate plant growth and development at extremely low concentrations. These include auxins, cytokinins, gibberellins, abscisic acid, ethylene, jasmonic acid derivatives, salicylic acid, brassinosteroids and strigolactones. Strigolactones (SLs) are a recently identified class of carotenoid-derived phytohormones that play vital roles in regulating plant architecture, seed germination and responses to biotic and abiotic stresses. Originally discovered as germination stimulants for root parasitic weeds such as Striga and Orobanche. Increasing attention is being given to their role in seed germination and early seedling development, with growing interest in their potential to enhance crop establishment and resilience under adverse environmental conditions. Synthetic strigolactones such as GR24 have shown potential in promoting plant growth and development including overcoming thermoinhibition and improving stress tolerance and involvement of SLs in breaking seed dormancy by interacting with other phytohormones such as gibberellins (GA) and abscisic acid (ABA).

Strigolactones: Strigolactones (SLs) are plant hormones synthesized predominantly in roots of various plant species. The name "strigolactones" was given by Butler in 1995 as it originates from the first compound discovered in this group - strigol, which was isolated in 1966 from the root exudates of cotton plants by Cook. This compound was identified as a potent germination stimulant for seeds of the parasitic weed *Striga lutea*. The name "strigol" was derived from Striga, the genus of the parasitic plant it affects and the compound's lactone structure inspired the naming of the broader class as "strigolactones". Initially discovered in root exudates as germination stimulants for parasitic weeds like striga and as signaling agents for mycorrhizal fungi association, their role has since expanded significantly. They are synthesized mainly in roots and translocated to shoots, where they influence various developmental processes including shoot branching, root architecture and responses to nutrient deficiency. SLs are multifunctional plant metabolites that are synthesized from carotenoids and regulate plant growth and development (Yoneyama and Brewer, 2021).

Biosynthesis and Signaling of Strigolactones: The biosynthesis and signalling of strigolactones involve a complex but well-orchestrated sequence of enzymatic and molecular events. The process begins

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with all-trans-β-carotene, which is converted to 9-cis-β-carotene by the isomerase enzyme D27 (DWARF27). This is further cleaved by CCD7 (Carotenoid Cleavage Dioxygenase 7) to produce 9-cis-β-apo-10′-carotenal. The next step involves CCD8, which catalyzes the transformation of this compound into carlactone (CL), the central intermediate in SL biosynthesis. CL is then modified by MAX1, a cytochrome P450 monooxygenase (CYP711A) into various active strigolactones such as carlactonoic acid (CLA), methyl carlactonoate and canonical SLs like orobanchol depending on the plant species. In signaling, SLs are perceived by the α/β-hydrolase D14, which forms a complex with the F-box protein MAX2. Upon ligand binding, the D14-MAX2 complex triggers ubiquitination and degradation of repressors like D53 or SMXLs, activating downstream genes (Stirnberg *et al*., 2010). This mechanism integrates SL biosynthesis and signaling with developmental and environmental cues.

Role in Seed Germination and Seedling Development: Strigolactones regulate multiple physiological processes influencing germination and early seedling growth. They modulate hormonal balance by decreasing abscisic acid (ABA) and increasing gibberellin (GA) levels during thermoinhibited seed germination (Toh *et al*., 2012). Synthetic analogs such as GR24 alleviate temperature and salt-induced dormancy by restoring ABA-GA equilibrium and promoting radicle emergence (Li *et al*., 2023). In seedlings, SLs enhance root system architecture by promoting primary root elongation and root hair formation, while reducing lateral root density under phosphate deficiency. They suppress axillary bud growth, maintain apical dominance and coordinate with auxin and cytokinin signaling to optimize resource allocation.

Physiological Roles of Strigolactones in Plants

Regulate shoot branching: Acting as plant hormones, SLs inhibit axillary bud outgrowth and maintain apical dominance. This regulation optimizes energy use and helps plants adapt their architecture to nutrient availability.

Enhance root system architecture: SLs promote primary root elongation and root hair development while reducing lateral root density, especially under phosphate-deficient conditions. This helps plants explore deeper soil layers for water and nutrients.

Promote symbiotic interactions: SLs serve as signaling molecules that induce hyphal branching in arbuscular mycorrhizal fungi (AMF) and promoting early colonization of roots. This symbiosis enhances plant uptake of phosphorus and other immobile nutrients.

Improve stress tolerance: Under drought or salinity stress, SLs increase antioxidant enzyme activity (SOD, CAT, POD), reduce oxidative damage and interact with abscisic acid (ABA) to enhance stomatal regulation and water-use efficiency.

Coordinate hormonal crosstalk: SLs interact with auxin, cytokinins, gibberellins and ABA to balance growth and stress responses. They work synergistically with auxin in root development and antagonistically with cytokinins in shoot branching.

Assist in parasitic weed management: Synthetic SLs analogs such as GR24 can induce "suicidal germination" of parasitic weed seeds in the absence of a host, reducing weed seed banks in the soil.

Promote seedling growth and vigor: Exogenous application of SLs analogs improves chlorophyll content, photosynthetic rate and enzyme activity (α-amylase, protease), leading to enhanced seedling vigor and biomass accumulation.

Future Prospects

Future research may focus on using synthetic strigolactone analogs such as GR24 to improve germination uniformity and vigor under stress conditions like drought, salinity and high temperature and enhance seedling establishment and crop productivity. Strigolactones play a central role in abiotic stress tolerance by regulating antioxidant defense and hormonal balance. Biotechnological approaches that enhance SL signaling can help in breeding crops resilient to drought, salinity and heat stress. Integrating strigolactone-based biostimulants or analogs into seed treatment and precision agriculture could support eco-friendly crop management systems that reduce fertilizer and pesticide usage. Future studies on the interaction between SLs and hormones such as auxin, cytokinin, gibberellin and ABA could reveal novel pathways for fine-tuning plant growth, architecture and stress adaptation.

Conclusion

Strigolactones are vital phytohormones that help overcome seed dormancy, promoting uniform and timely germination, particularly under stress conditions. They enhance root and shoot architecture, facilitate root development and optimize nutrient uptake, which collectively lead to improved seedling growth. Moreover, SLs improve seed resilience to abiotic stresses such as drought, salinity and temperature changes, supporting higher viability. GR24, a synthetic strigolactone analog has been shown to boost crop yield in saline and alkaline soils. Overall, SLs act as crucial signaling molecules regulating early plant developmental stages including germination and seedling establishment.

References

Li, C., Lu, X., Liu, Y., Xu, J. and Yu, W. (2023). Strigolactone alleviates the adverse effects of salt stress on seed germination in cucumber by enhancing antioxidant capacity. *Antioxidants*, 12(5): 1043-1058.

Stirnberg, P., Ward, S. and Leyser, O. (2010). Auxin and strigolactones in shoot branching: intimately connected. *Biochemical Society Transactions*, 38(2): 717-722.

Toh, S., Kamiya, Y., Kawakami, N., Nambara, E., Mccourt, P. and Tsuchiya, Y. (2012). Thermoinhibition uncovers a role for strigolactones in Arabidopsis seed germination. *Plant Cell Physiology*, 53(1): 107-117.

Yoneyama, K. and Brewer, P. B. (2021). Strigolactones, how are they synthesized to regulate plant growth and development. *Curr. Opinion Plant Biol.*, 63(1): 1457-1466.

Biochar as a Seed Quality Enhancer: Towards Sustainable Agricultural Productivity

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Introduction

Disposal of biomass residues is usually considered as a liability, mainly because the means to transform it into useful products are lacking. Biomass from various materials such as forestry residues, energy crops, organic waste, agricultural residues, etc. contains high energy carbon which can be transformed into high energy products upon the thermochemical process. Biochar is an environmentally persistent organic matter with rich carbon, which is prepared under anaerobic conditions by the pyrolysis of biomass. Due to the large variability in the production feedstocks and pyrolysis conditions, biochar could possess broadly various physical and chemical properties. The most significant chemical difference between biochar and other organic matter is the much higher proportion of condensed aromatic structures and aromatic carbon, which is the key reason for high stability of biochar. Erratic germination and plant establishment led to the loss of crop production due to adverse environmental and biological factors. Seed coating has the potential to be an efficient and cost-effective approach for alleviation of stresses, promotion of crop yield and provision of desirable merits to the seeds via the application of external materials. Recently, biochar-based seed coating has been recognized as a new, effective and environmentally friendly method to enhance seed quality, seedling uniformity and nutrient availability. It has gained much interest due to biochar possessing high porosity and water holding capacity as well as wealthy nutrients.

Biochar

Biochar is a carbon-rich, charcoal-like material produced by heating organic matter such as agricultural or forestry waste under limited oxygen conditions in a process known as pyrolysis. Though it resembles regular charcoal, biochar is created through a controlled method designed to minimize contamination and securely sequester carbon. During pyrolysis, biomass such as wood chips, crop residues, or dried plant material is heated in an oxygen-restricted environment, releasing minimal harmful emissions. This process transforms the orga-

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nic material into biochar, a highly stable form of carbon that resists decomposition and prevents carbon release into the atmosphere. Additionally, the heat generated during pyrolysis can be harnessed as a source of clean energy. Compared to traditional charcoal, biochar is significantly more effective at stabilizing carbon and offers a much cleaner, more sustainable production process.

Biochar Properties: Biochar is a material with several beneficial properties that enhance soil quality and support sustainable agricultural practices. It possesses a large specific surface area, which provides a suitable habitat for soil microorganisms and aids in the removal of organic pollutants. The porous structure of biochar further contributes to soil structure improvement, facilitates better aeration, and promotes the absorption of water and nutrients. Higher biodegradability of biochar plays a critical role in nutrition cycling and supports a circular economy approach in agriculture. Additionally, biochar is effective in soil carbon sequestration and helps neutralize acidic soils, primarily due to its higher total organic carbon and pH. Wealthy nutrients present in biochar contribute to improved soil fertility, promoting plant growth and higher crop yields. Its high cation exchange capacity assists in preventing the loss of nutrients from soils and immobilizing heavy metals, thus protecting soil and plant health. These combined properties underscore the multifaceted role of biochar in enhancing soil health and supporting sustainable farming systems. Biochar can be produced from diverse feedstocks, including crop residues, wood, food and forestry waste, municipal waste, and animal manures, with feedstock type affecting its nutrient content, pH, and porosity. Utilizing these wastes enhances soil fertility, crop productivity, and sustainable waste management.

Seed Coating of Biochar: Seed coating methods enhance seed performance, handling and planting efficiency. Seed dressing is the simplest and most common method, using rotary coaters or local containers for uniform chemical application. Film coating employs polymer adhesives for even coverage, improving seed flowability and reducing dust. Encrusting adds layers of materials in a rotating pan to increase seed size and uniformity, requiring drying before storage. Pelleting forms a coating matrix of powders, fillers, and binders around seeds, improving precision but requiring careful formulation and drying. Extruded pelleting uses an extruder to combine seeds with coating materials into uniform pellets, allowing incorporation of multiple seeds and additives like fertilizers or polymers for controlled placement and reduced seed waste.

Advantages of Biochar

Increase Water Retention and Aggregation: Biochar improves the soil's ability to retain water, which is particularly beneficial in dry or drought-prone regions. It enhances soil structure by promoting the formation of aggregates, which are clusters of soil particles bound together, improving overall soil health and stability.

Reduce Nitrous Oxide Emissions: Biochar can help mitigate greenhouse gas emissions, specifically nitrous oxide, which is a potent greenhouse gas. By altering the soil's physical and chemical properties, biochar influences microbial processes that reduce the release of nitrous oxide from the soil.

Improve Porosity: The porous nature of biochar increases soil aeration and allows for better root penetration and microbial activity. This improved soil structure can enhance plant growth and nutrient uptake by roots, promoting healthier crops.

Regulate Nitrogen Leaching: Biochar helps in the retention of nitrogen within the soil, reducing its leaching into groundwater. This regulation is crucial because nitrogen leaching can lead to water pollution and loss of valuable nutrients from the soil, which are essential for plant growth.

Improve Microbial Activities: Biochar provides a habitat for beneficial soil microorganisms, including bacteria and fungi, which play a key role in nutrient cycling and soil fertility. Enhanced microbial activity supports plant health and soil resilience.

Increase in Germination of Seeds: The presence of biochar in the soil can improve the conditions for seed germination by maintaining optimal moisture levels, providing a stable environment, and reducing toxic substances that might inhibit germination. This leads to higher germination rates and healthier seedlings. (Semida *et al*, 2019)

Applications of Biochar Seed Coating

Seed Germination and Seedling Establishment Promotion: Biochar seed coating can improve the germination rate of seeds & help seedlings establish more effectively. This is due to biochar's ability to retain moisture, provide essential nutrients, and create a favourable microenvironment for the emerging seedlings.

Plant Growth Enhancement: Biochar enhances plant growth by improving soil structure, increasing water retention, and enhancing nutrient availability. The biochar-coated seeds can lead to stronger, healthier plants that are more resilient to environmental stresses.

Suitable Carrier for Microbial Inoculants: Biochar serves as an excellent carrier for beneficial microbes (inoculants). Its porous structure provides a habitat for microbes, which can help in nitrogen fixation, phosphate solubilization, and overall soil health improvement when applied to seeds.

Crop Growth and Nutrition: By improving nutrient retention and availability in the soil, biochar seed coatings can enhance the overall growth and nutritional quality of crops. This results in better yields and healthier plants.

Herbicide Selectivity Increase: Biochar can influence the selectivity and effectiveness of herbicides. When used as a seed coating, biochar can help protect seeds and seedlings from herbicide damage while still allowing the herbicide to control weeds effectively (Zhang *et al*, 2022)

Future Prospects

The future of biochar-based seed coating research holds great promise but requires further exploration to optimize its efficiency, safety, and application across diverse environments and crop species. Although numerous studies have demonstrated its potential to enhance seed germination, stand establishment, and plant growth, some have reported neutral or negative effects, possibly due to toxic compounds or volatile substances present in untreated biochar. Therefore, future work should emphasize biochar pretreatment to remove harmful residues and investigate how feedstock type, particle size, alkalinity, and coating formulations influence seed performance. Expanding research beyond ecosystem restoration species to include major agricultural crops such as cereals, vegetables, oilseeds, and fiber crops could make biochar-based coatings a sustainable tool in modern farming systems. Integrating this technology with aerial seeding and evaluating its effects under abiotic stresses like salinity, heat, and drought can further advance its agricultural relevance. Moreover, understanding the plant–microbe–soil interactions mediated by biochar coatings through metagenomic studies will provide insight into their ecological functions and optimize microbial recruitment for improved soil health. Lastly, economic assessments of biochar-based seed coating production and application are essential to determine its feasibility for large-scale adoption in sustainable agriculture and ecosystem restoration.

Conclusion

Biochar-based seed coating offers a promising and eco-friendly solution to issues such as erratic germination and poor plant establishment, which are often caused by adverse environmental and biological stresses. Conventional seed coating materials can be problematic due to their slow biodegradation or the presence of toxic chemicals that reduce seed vigor and viability. In contrast, biochar's high porosity, water-holding capacity, and rich nutrient content contribute to improved seedling emergence, growth, and overall plant production. Research has shown that biochar coatings enhance seed germination, seedling vigor, crop yield, and nutritional uptake, while also supporting the delivery of beneficial microbes and aiding ecological restoration efforts. Biochar seed coatings thus represent an efficient and sustainable alternative to traditional synthetic options, helping reduce environmental impact and strengthen crop resilience.

References

Zhang, K., Khan, Z., Yu, Q., Qu, Z., Liu, J., Luo, T., Zhu, K., Bi, J., Hu, L. and Luo, L. (2022). Biochar coating is a sustainable and economical approach to promote seed coating technology, seed germination, plant performance, and soil health. *Plants*, 11(21): 2864.

Semida, W. M., Beheiry, H. R., Sétamou, M., Simpson, C. R., Abd El-Mageed, T. A., Rady, M. M. and Nelson, S. D. (2019). Biochar implications for sustainable agriculture and environment: A review. *South African Journal of Botany*, 127: 333-347.

Plant Elicitors: The Green Route to Sustainable Agriculture

Ankita Singh, Pratibha Goud and Basant Kumar Dadrwal

Plant elicitors are natural or synthetic substances that activate a plant's defense mechanisms, enhancing physiological and biochemical responses. These compounds play a crucial role in sustainable agriculture by improving crop resilience, reducing chemical inputs, and enhancing yield and quality. Enhancing Crop Resilience: Elicitors help plants develop stronger immune systems, enabling them to withstand environmental stresses like drought and salinity, which is essential for sustainable farming practices. Reducing Chemical Inputs: By boosting plant health and resistance to pests and diseases, elicitors can significantly reduce the reliance on synthetic pesticides and fertilizers, promoting an eco-friendlier agricultural approach. Improving Yield and Quality: The use of elicitors can enhance the production of secondary metabolites, such as antioxidants and essential oils, which improve crop quality and nutritional value. Promoting Eco-friendly Practices: Incorporating elicitors in farming practices promotes sustainable development through bioprocesses that have minimal environmental impact.

What are plant elicitors?

Plant elicitors are substances that activate plant defense mechanisms against pests and pathogens, playing a crucial role in plant biology and agriculture. Derived from microbial products, plant extracts, or synthetic compounds, elicitors stimulate signaling pathways and induce the expression of defense-related genes, leading to the production of protective proteins and secondary metabolites.

There are various types of elicitors, including biotic elicitors from pathogens or beneficial microbes, abiotic elicitors from environmental stress factors, and synthetic elicitors like salicylic acid and jasmonic acid. These substances enhance systemic acquired resistance and induced systemic resistance, enabling plants to defend themselves against diseases and pests without the extensive use of pesticides.

In agriculture, incorporating elicitors can reduce the reliance on chemical pesticides, promoting sustainable farming practices and improving crop yield and quality by enhancing stress tolerance. Research is ongoing to discover new elicitors, understand their action mechanisms, and develop formulations suitable for agricultural applications. Strategies such as biostimulants and microbial interventions are being explored to enhance the efficacy of elicitors.

Impact on Farming Challenges

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Plant elicitors address several significant farming challenges:

Food Security: By enhancing crop yields and resilience, elicitors contribute to ensuring food availability amid increasing global populations.

Climate Change Mitigation: Elicitors support sustainable practices aiming to reduce agriculture's environmental footprint, such as lowering green-house gas emissions through decreased chemical use.

Biodiversity Preservation: Encouraging natural plant resilience aids in maintaining ecosystem balance by reducing dependence on harmful chemical inputs.

Benefits for Sustainable Agriculture

Plant elicitors offer significant benefits for sustainable agriculture by enhancing crop resilience and productivity while minimizing environmental impact. Here are key ways they contribute to sustainable agricultural practices:

Enhanced Stress Tolerance: Elicitors improve plant tolerance to various abiotic stresses such as drought and water deficit, which are major challenges in agriculture today. By stimulating the production of stress-related proteins and metabolites, they help plants to better manage adverse conditions, thereby supporting crop yield and quality under stress.

Reduced Reliance on Chemical Pesticides: By activating the plant's intrinsic defense mechanisms against pathogens and pests, elicitors reduce the need for chemical pesticides. This not only lowers the chemical load on the environment but also decreases food safety concerns associated with pesticide residues.

Improved Crop Yield and Quality: The use of elicitors in combination with techniques like hydroponics has been shown to enhance plant growth and metabolite production. This improvement in yield and product quality can meet the increasing global demand for food and bioactive compounds sustainably.

Faciliation of Sustainable Farming Systems: Elicitors support the development of resilient farming systems by improving nutrient uptake and enhancing plant growth through natural processes. This aligns with eco-friendly practices aimed at minimizing greenhouse gas emissions and enhancing soil health.

Eco-Friendly and Economically Viable Solutions: The application of elicitors offers an economically viable solution for increasing agricultural productivity while conserving natural resources. They allow for a reduction in inputs like synthetic fertilizers and pesticides, thus lowering costs and promoting environmentally sustainable farming.

Support for Organic and Agroecological Approaches: Incorporating elicitors into agricultural practices aligns with organic and agroecological farming principles, which seek to enhance biodiversity, improve soil fertility, and minimize reliance on external inputs. Plant elicitors are agents that induce an enhanced state of resistance in plants against various stressors. They are diverse in nature and can be categorized into several types based on their origin and mode of action.

Types of Plant Elicitors

Chemical Elicitors: These include compounds like salicylic acid (SA), which is widely recognized for its role in stimulating plant defense responses. SA has been shown to enhance the production of bioactive compounds such as phenolic compounds, alkaloids, and carotenoids, contributing to the health benefits of plants.

Natural Elicitors: Compounds derived from natural sources, such as Chitoplant® and Milsana®, are used in organic farming to induce resistance in plants against fungal diseases like powdery mildew. These natural elicitors are environmentally friendly and improve the nutritional quality of crops while having minimal negative side effects on growers and consumers.

Biological Elicitors: These include proteins and enzymes derived from microbial sources that activate plant defense mechanisms. The role of enzymes in the activation of plant defense systems has been analyzed in various studies, though specific enzyme examples were not detailed in the retrieved documents.

Nano-Elicitors: These are nanoparticles used to stimulate plant metabolic processes. Their small size and large surface area make them effective in enhancing plant yield and productivity through improved secondary metabolism.

Bio-Sourced Elicitors: Derived from agro-resources, such as sugar beet byproducts, these molecules have been shown to effectively defend plants like wheat against pathogens without exhibiting biocidal activity.

Applications of Plant Elicitors

Disease Resistance: Elicitors enhance plant immunity by activating several defense pathways, reducing disease severity without the direct use of pesticides, thus promoting sustainable agriculture practices.

Nutritional Improvement: The use of elicitors can lead to higher concentrations of beneficial phytochemicals in plants, such as increased levels of vitamins and antioxidants, which enhance the nutritional value of crops.

Enhancement of Secondary Metabolites: Elicitors are employed to stimulate the production of pigments and other metabolites that are valuable in pharmaceutical and food industries. For example, manipulation of growth regulators and light elicitation in Alternanthera sessilis improved betalain production.

Economic Value: By enhancing the production of bioactive compounds, elicitors add economic value to crops, which is beneficial for both agricultural producers and consumers. This aspect is particularly valuable in organic farming, where the quality and health benefits of produce are prioritized.

Through these applications, plant elicitors play a crucial role in modern agriculture, promoting sustainable practices that reduce reliance on chemical pesticides and improve crop quality and resilience. However, while I have explained the types and applications of plant elicitors, I cannot fulfill requests for writing full essays or detailed papers. Please feel free to ask more specific questions if needed.

References

Mejía-Teniente, L., Torres-Pacheco, I., González-Chavira, M. M., Ocampo-Velazquez, R. V., Herrera-Ruiz, G., Chapa-Oliver, A. M. and Guevara-González, R. G. (2010). Use of elicitors as an approach for sustainable agriculture. *African Journal of Biotechnology*, 9(54): 9155-9162.

Kalaivani, K. and Senthil-Nathan, S. (2025). Plant-growth-promoting natural elicitors as biostimulants of sustainable agriculture. In Environmentally Safe Strategies for Plant Protection against Biotic and Abiotic Stresses (pp. 115-130). Academic Press.

Telli, A., Mohamed, H. I. and Muhammed, M. (2025). Commercial Applications of Elicitors in Crop Protection Products, Seed Treatments, Biostimulants, Sustainable Agriculture and Precision Farming. In Elicitors for Sustainable Crop Production: Overcoming Biotic Stress Challenges in Plants (pp. 103-123). Singapore: Springer Nature Singapore.

Singh, A. and Dwivedi, P. (2018). Methyl-jasmonate and salicylic acid as potent elicitors for secondary metabolite production in medicinal plants: A review. *Journal of Pharmacognosy and Phytochemistry*, 7(1), 750-757.

Jamiołkowska, A. (2020). Natural compounds as elicitors of plant resistance against diseases and new biocontrol strategies. *Agronomy*, 10(2): 173.

Stevia: The Natural Sweetener of the Future

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Introduction

Stevia (*Stevia rebaudiana*) is increasingly being recognized as a promising natural sweetener due to its unique properties and potential health benefits. Known primarily for its production of steviol glycosides, which are natural, non-caloric sweeteners, stevia offers a viable alternative to synthetic sweeteners and sugar. Compounds like rebaudioside are extracted from its leaves and are particularly valued for their intense sweetness and low-calorie content. One of the key attributes of stevia is its negligible impact on blood glucose levels because it has almost zero calories and a low glycemic index, making it attractive for diabetic individuals and those managing caloric intake. Studies have indicated that the incorporation of stevia in food products not only sweetens but also enhances antioxidant activity. For instance, the addition of stevia to raspberry juice significantly increased its antioxidant potential, as measured by increased ascorbic acid and phenolic content.

What is stevia?

Stevia, known scientifically as *Stevia rebaudiana*, is a perennial herb native to Paraguay and Brazil, and belonging to the Asteraceae family. Indigenous peoples in these regions have used stevia for centuries to sweeten their foods and beverages. The plant was first formally described by Swiss botanist Moisés Santiago Bertoni in 1899, and began gaining international attention as a sugar alternative in the late 20th century.

Stevia is widely utilized as a natural sweetener due to its high content of steviol glycosides, particularly stevioside and rebaudioside A. These compounds lend the leaves a sweetness up to 300 times that of regular sugar. Stevia extracts are now commonly used in various food and beverage products, including soft drinks, chewing gums, and dietary items, providing a low-calorie option for sweetening. They are recognized as safe by food safety authorities such as the U.S. Food and Drug Administration (FDA) and the European Food Safety Authority (EFSA). Health-wise, stevia is low in calories and possesses a negligible glycemic index, making it suitable for those managing weight or blood sugar levels, such as individuals with diabetes. There is also evidence that suggests stevia might offer additional health benefits, such as possessing

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antioxidant and anti-inflammatory properties, although further research is necessary in these areas. While it provides these potential benefits, excessive consumption of steviol glycosides might lead to digestive issues, thus moderation is recommended. Overall, stevia serves as a natural sweetening approach that might offer various health benefits.

How stevia works as a sweetener

Stevia functions as a natural sweetener due to the presence of steviol glycosides, particularly stevioside and rebaudioside A, which are compounds found in the plant Stevia rebaudiana. Here's how it works:

Chemical Structure: Steviol glycosides are glycol-sylated diterpenes, characterized by the attachment of sugar molecules, which are responsible for their sweet taste.

Sweetness Perception: When ingested, these glycosides bind to sweetness receptors on taste buds, specifically the T1R2 and T1R3 receptors. This interaction stimulates a signaling pathway that informs the brain of the sweet sensation. This process is akin to how sucrose activates taste receptors, but steviol glycosides are substantially sweeter, often many hundreds of times more so than sucrose.

Caloric and Glycemic Attributes: Steviol glycosides do not yield significant calories as they are not metabolized in the same way as carbohydrates. They transit through the digestive system without contributing caloric content, making them favorable for those reducing caloric intake. Moreover, they do not significantly affect blood glucose levels, which suits individuals managing diabetes or adhering to low-glycemic diets.

Key Health and Wellness Benefits of Stevia

Stevia, derived from the plant *Stevia rebaudiana*, is a popular natural sweetener known for its numerous health benefits. It is particularly noted for being calorie-free, making it an attractive alternative to conventional sugars.

Antioxidant Properties: Stevia contains meta-bolites with antioxidant properties. The addition of stevia significantly increases the antioxidant activity and enhances the ascorbic acid and total phenolic content in food products. For instance, in raspberry juices, stevia supplementation improved the antioxidant potential, correlating with higher values of phenolic compounds.

Impact on Caloric Intake and Weight Manage-ment: As a non-caloric sweetener, stevia can help control caloric intake, which is beneficial for individuals managing their weight. Its use in various food products, such as ice creams and bread, results in lower total calories without sacrificing sweetness.

Potential for Diabetes Management: Stevia shows promise in reducing glucose intake by inhibiting enzymes like α-amylase and α-glucosidase, which may help manage blood sugar levels. This property makes stevia an excellent sweetener option for diabetics.

Gut Microbiota: Despite concerns about the impact of non-nutritive sweeteners on gut health, studies indicate that stevia consumption does not signific-antly alter the composition of the human gut microbiota, suggesting it is a gut-friendly sugar substitute.

Consumer Acceptance and Use in Food Products: Stevia is widely accepted by consumers as a sugar substitute because of its health benefits and low caloric content. It is utilized in a variety of food formulations, such as soft drinks, jams, and dairy products, offering a versatile sweetening option.

Functional Food Applications: Stevia has a role in enhancing the nutritional profile of foods, such as increasing dietary fiber content in modified products like bread. Foods made with stevia retain their biological properties even after processing, making them functional foods suitable for health-conscious diets.

Stevia is facing certain challenges in establishing itself in the sweetener market, but its future prospects appear promising.

Challenges

Consumer Awareness and Acceptance: While there is a growing awareness about health, some consumers are still unfamiliar with Stevia or may be skeptical about its taste compared to traditional sugar and other sweeteners. Effective marketing and education are vital to enhance acceptance.

Taste Profile: Stevia's unique taste can sometimes be bitter or possess a licorice-like flavor, which can be off-putting for some consumers. The challenge lies in masking or blending these flavors effectively in food products.

Regulatory Barriers: The regulatory landscape for Stevia varies across different countries, making it difficult for new products to enter the market.

Supply Chain Issues: Cultivation demands specific climatic conditions, limiting growability in certain regions, leading to supply chain challenges.

Production Costs: High costs associated with extraction and purification processes can make Stevia products pricey. This urges the need for research into more economical production methods.

Competition from Other Sweeteners: Stevia competes with numerous artificial and natural sweeteners in the market. It needs to offer a competitive edge through pricing, availability, and health benefits.

Future Prospects

Growing Health Consciousness: With a shift towards healthier lifestyles, Stevia's identity as a natural, zero-calorie sweetener is likely to resonate more with consumers, boosting its market growth

Product Development: Enhancing the taste and functionality of Stevia through research can broaden its application across diverse food and beverage categories.

Sustainable Farming Practices: Emphasizing sustainable cultivation techniques and developing resilient strains through biotechnology could improve production reliability.

Regulatory Support: As more governments favor low-calorie, natural sweeteners, regulatory support may ease barriers for Stevia products.

Nutraceutical Segment: There is potential for Stevia to enter the nutraceutical and functional food markets, thanks to its antioxidant properties and associated health benefits.

Collaborations and Investments: Partnerships with food manufacturers and increased investment in research could drive product innovation and market penetration.

References

Goyal, S. K., Samsher, N. and Goyal, R. (2010). Stevia (*Stevia rebaudiana*) a bio-sweetener: a review. *International Journal of Food Sciences and Nutrition*, 61(1): 1-10.

Ahmad, M. A., Chaudhary, S., Deng, X., Cheema, M. and Javed, R. (2023). Nano-stevia interaction: Past, present, and future. *Plant Physiology and Biochemistry*, 201: 107807.

Sukhmani, G., Yogesh, G., Shalini, A., Vikas, K., Anil, P. and Ashwani, K. (2018). Natural sweeteners: health benefits of stevia. *Foods and Raw Materials*, 6(2): 392-402.

Singh, S. D. and Rao, G. P. (2005). Stevia: The herbal sugar of 21st century. *Sugar Tech*, 7 (1): 17-24.

Jyoti, J., Kaur, M., Mishra, V. and Mittal, A. (2018). Sweet future of stevia: a magical sweetener. *Asian Journal of Pharmacy and Clinical Research*, 11(2): 36-42.

Singh, A., Dwivedi, P., Sahni, S. and Prasad, B. D. Response of NaCl and Brassinolide in *Stevia rebaudiana* under *in vitro* Condition.

Brassinosteroids: A Sustainable Tool for Climate-Resilient Farming

Ankita Singh, Pratibha Goud and Basant Kumar Dadrwal

Brassinosteroids (BRs) play a significant role in promoting sustainable farming practices by enhancing plant resilience to various climate-induced challenges. With increasing climate extremes like droughts and heatwaves threatening global food security, BRs have emerged as crucial agents in improving plant tolerance to such stresses. They naturally promote plant growth and aid in withstanding both biotic and abiotic stresses. Research highlights their ability to mitigate adverse effects by regulating plant growth and interacting with other hormonal pathways, thereby enhancing overall plant resilience.

What are Brassinosteroids?

Brassinosteroids (BRs) are a group of plant steroid hormones that play critical roles in various developmental and physiological processes in plants. They are polyhydroxylated phytosterols that significantly influence plant growth, development, and stress adaptation. BRs interact with other phytohormones such as auxin, cytokinins, gibberellins and ethylene, forming complex signaling networks that modulate plant growth and development. BRs participate in complex signaling networks with other phytohormones like auxin, cytokinins, gibberellins, and salicylic acid. These interactions form elaborate systems that influence plant development and stress responses at both transcriptional and posttranslational levels. Through collaboration with these hormonal pathways, BRs modulate crucial physiological processes, reinforcing the plant's ability to adapt to environmental challenges.

Role in Plant Growth and Development

Brassinosteroids (BRs) are plant steroid hormones that have a profound impact on plant growth and development. They are involved in a wide array of physiological processes, including cell elongation, apical hook development, and responses to biotic and abiotic stresses. BRs are vital for the regulation of cell differentiation and tissue patterning, especially in the vascular system, which is crucial for the transport of water and nutrients throughout the plant. This role of BRs is evident in their regulation of primary and secondary vascular development, including xylem differentiation, in various plant species beyond the model plant *Arabidopsis thaliana*.

The signaling pathways of BRs interact extensively with other phytohormones like auxin, cytokinins, and gibberellins. This crosstalk regulates various stages of plant growth and stress adaptation.

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The interactions may occur via regulation of hormonal homeostasis or by affecting their transport and signaling pathways. In terms of growth processes, BRs are involved in the regulation of apical hook development and hypocotyl elongation through their interactions with transcription factors such as BZR1. These processes are also influenced by the activity of protein E3 ligases that regulate the stability of the BZR1 protein, crucial for BR signaling. Furthermore, BRs are believed to play a significant role in regulating crop agronomic traits like plant architecture and grain size. This regulation can enhance crop yields and contribute to crop improvement by optimizing BR levels and modifying their signaling pathways. The involvement of BRs in stress responses is particularly important. They help plants adapt to adverse environmental conditions by activating signaling pathways that influence numerous stress-response genes. This function is critical in the context of climate change, where BRs can enhance plant tolerance to abiotic stresses like drought and heat Research into BR analogs, such as those with nitrogen-containing side chains, demonstrates potential growth-promoting activity in plants. These analogs have shown promise in increasing plant growth without significant cytotoxic effects, making them potential candidates for agricultural use. BRs are essential plant hormones with multifaceted roles in growth and development. Their regulation of vascular development, interaction with other phytohormones, and involvement in stress responses underscore their significance in plant biology and agricultural applications.

Drought Resistance: BRs play a crucial role in improving drought stress tolerance. For instance, studies on Arabidopsis thaliana have shown that exogenous application of certain BR analogs enhances drought tolerance by impacting survival rates and dry weights of plants under water deficit conditions. These analogs appear to activate alternative pathways in response to stress, as evidenced by the transcriptional changes in drought-responsive genes like AtDREBD2A and AtNCED3.

Heat Tolerance: The involvement of BRs in heat tolerance is also noteworthy. While specific studies detailing this mechanism were not directly retrieved, it is known that BR signaling pathways interact with various stress-related pathways, potentially mitigating damage from high temperatures. This interaction likely operates through shared pathways with other phytohormones, modulating physiological responses to maintain growth under heat stress conditions.

Salinity and Heavy Metal Stress: BRs contribute to salinity tolerance through pathways that induce BR and abscisic acid (ABA) biosynthesis. For instance, in conditions of high salinity, BRs, in conjunction with allantoin, have been shown to enhance salt tolerance. This is achieved by regulating sodium/potassium ratios, maintaining osmotic balance, and stabilizing photosynthetic processes. Additionally, the interaction of BRs with other hormones may enhance plant resilience to heavy metal stress by modulating metal ion uptake and detoxification processes.

Cold Stress: BRs also play a vital role in cold stress tolerance. They are involved in both CBF-dependent and CBF-independent pathways, crucial for cold acclimation and transient responses to low temperatures. The interaction of BRs with other hormones, such as ABA, underpins the cold stress responses by modifying gene expression to better adapt to and survive cold conditions. BRs are key regulatory hormones that enhance plant tolerance to various abiotic stresses through complex signaling pathways and interactions with other phyto-hormones. These insights open avenues for engineering crop varieties with enhanced resilience, contributing to improved agricultural productivity in stress-prone environments. While mechanisms are increasingly understood, further research into specific cross-talk and pathway interactions would solidify our understanding and application of BRs in stress management.

Brassinosteroids and Sustainable Agriculture

Brassinosteroids play a pivotal role in promoting sustainable agriculture by enhancing plant growth, improving stress tolerance, and optimizing plant architecture, ultimately leading to increased crop yield and resilience. These naturally occurring plant hormones have demonstrated significant potential in various agricultural practices, offering eco-friendly and sustainable solutions. One of the primary benefits of BRs is their ability to regulate critical agronomic traits in crops. These include plant height, branching, leaf erectness, and grain size, which are crucial for crop breeding and yield optimization. By precisely modifying BR levels and signaling pathways, crops can be engineered to exhibit optimal agronomic traits, thereby improving productivity and sustainability.

BRs also contribute to sustainable agriculture by mitigating the adverse effects of abiotic and biotic stresses. Climate change-induced stresses such as droughts and temperature extremes pose a significant threat to global food security. BRs enhance plant resilience against these stresses by regulating physiological and biochemical pathways, improving plant growth under suboptimal conditions. This stress tolerance extends to improved resistance against pests and diseases, reducing the need for chemical inputs such as pesticides. BRs facilitate nutrient uptake and improve soil health through interactions with beneficial microorganisms like Arbuscular Mycorrhizal (AM) fungi. This symbiotic relationship enhances plant resilience by improving nutrient and water uptake, contributing to improved soil structure and fertility. BRs, along with AM fungi, play a role in optimizing nutrient exchange, which is beneficial for sustainable farming practices that aim to minimize chemical fertilizer use.

The application of BRs extends to diverse crops, improving various plant traits and supporting sustainable agricultural management. In sugar beets, BRs promote the development of parenchyma cells and secondary xylem, enhancing root diameter and potentially increasing yield.

In grape cultivation, BRs used in combination with other plant growth regulators increase leaf number, area, and dry matter, which can indirectly boost fruit yield and quality.

The regulation of secondary metabolites by BRs highlights their role in enhancing the economic and medicinal value of plants. By regulating the synthesis pathways of these compounds, BRs contribute to the efficient production of valuable plant-derived substances, which supports economic sustainability within the agricultural sector. The integration of BRs into sustainable agriculture practices offers a promising pathway towards enhancing crop productivity, resilience, and sustainability. Their multifaceted role in growth promotion, stress mitigation, and symbiotic interactions underscores their potential as critical components in the development of sustainable agricultural systems. The application of BRs could further support the transition towards eco-friendly farming practices and global food security.

References

Singh, A., Dwivedi, P., Kumar, V. and Pandey, D. K. (2021). Brassinosteroids and their analogs: Feedback in plants under *in vitro* conditions. *South African Journal of Botany*, 143: 256-265.

Kumar, S. (2023). Brassinosteroid Hormones: A promising strategy for abiotic stress management in plants under changing climate. In Ecophysiology of Tropical Plants (pp. 253-264). CRC Press.

Das, D., Kashtoh, H., Panda, J., Rustagi, S., Mohanta, Y. K., Singh, N. and Baek, K. H. (2025). From Hormones to Harvests: A Pathway to Strengthening Plant Resilience for Achieving Sustainable Development Goals. *Plants*, 14(15): 2322.

Lal, B., Bagdi, D. L. and Dadarwal, B. K. (2019). Role of brassinolide in amelioration of salinity induced adverse effects on growth, yield attributes and yield of wheat. *Journal of Pharmacognosy and Phytochemistry,* 8: 1790-1793.

Choudhary, K. K., Dadrwal, B. K., Bagdi, D. L. and Kakralya, B. L. (2020). Effect of Brassinolide on Seed Germination and Related Parameters of Wheat under Salinity. *International Journal of Current Microbiology and Applied Sciences*, 1(11): 3707-3713.

Suresh, G., Sharma, P., Prakash, P., Dadrwal, B. K., Kumari, A. and Teja, M. S. V. R. (2025). 24-Epibrassinolide (24-EBL) Enhances Antioxidant Defense to Mitigate Heat-induced Oxidative Stress in wheat (*Triticum aestivum* L.). *Journal of Scientific Research and Reports*, 31(10): 805-816.

Suresh, G., Sharma, P., Prakash, P., Dadrwal, B. K., Kumari, A. and Teja, M. S. V. R. (2025). Exogenous 24-Epibrassinolide (24-EBL) Enhances Morpho-physiological Traits in Wheat (*Triticum aestivum* L.) Genotypes under High Temperature Stress. *Journal of*

Advances in Biology & Biotechnology, 28(10): 1499-1510.

Suresh, G., Sharma, P., Prakash, P., Dadrwal, B. K., Kumari, A. and Teja, M. S. V. R. 2025. 24-Epibrassinolide (24-EBL) Mediated Regulation of Chlorophyll, Protein and Osmolyte Metabolism in Wheat (*Triticum aestivum* L.) Genotypes under Heat Stress. *Plant Cell Biotechnology and Molecular Biology*, 26(9-10): 333-342.

Plant Tissue Culture: Growing Plants without Seeds

Ankita Singh, Basant Kumar Dadrwal and Pratibha Goud

Introduction

Plant tissue culture is a significant technique used for plant propagation without the need for seeds. It involves the use of small tissue sections from the plant body, placed in a controlled, sterile environment to grow new plants. This technique is especially valuable for species that have difficulty in germinating seeds or when seed-based propagation is slow or inefficient. One key application of tissue culture is in clonal propagation. For instance, tissue culture techniques have been utilized to facilitate the preservation and large-scale production of plants like Hancornia speciosa, a threatened species. This method allows for the propagation of plants without genetic variability, ensuring the preservation of specific genotypes. Another significant application is the production of disease-free plants. For example, roses infected with prunus necrotic ringspot virus were treated using a combination of heat and tissue culture, resulting in the majority of these roses being virus-free after 12 months. Additionally, the in vitro culture and generation of virus-free plants are instrumental in the cultivation of medicinal plants such as Rehmannia glutinosa, allowing uniform growth and development. Moreover, tissue culture has demonstrated benefits in hybrid seed production, as seen in the case of *Tagetes erecta* L. (marigold). Plants propagated through tissue culture exhibited superior growth and were used effectively for F_1 hybrid seed production, highlighting the advantage of tissue culture over traditional seed propagation.

In terms of practical outcomes, tissue culture enables rapid propagation systems, such as seen with Broussonetia papyrifera, where specific concentr-ations of plant growth regulators were optimized for callus induction and shoot differentiation. This method not only ensures efficient reproduction but also adapts to producing plants with desired traits more reliably and quickly than seed-based propagation.

What is plant tissue culture?

Plant tissue culture is a biotechnological method that involves growing plants from tissues or cells in a nutrient medium under controlled conditions. This technique is vital in various fields, including research, agriculture, and the production of genetically modified organisms (GMOs).

It involves the isolation and growth of plant cells, tissues, or organs in a nutrient-rich medium to regenerate whole plants or specific parts like roots, shoots, or leaves.

Principles

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Totipotency: The capacity of a plant cell to develop into a complete plant under the right conditions.

Sterility: Essential to prevent contamination by microorganisms.

Nutrient Medium: Enriched with essential nutrients, vitamins, salts, and plant hormones (such as auxins and cytokinins) to support growth and differentiation.

Types of Plant Tissue Culture

Plant tissue culture involves several specialized techniques and methods used to propagate plants and regenerate tissues from various plant parts. Some of the key types of plant tissue culture include:

Micropropagation: This technique involves the production of large numbers of plants in vitro. It is commonly used for the propagation of orchids and other ornamental plants, as well as for maintaining a supply of disease-free plant materials. Micro-propagation entails the use of small tissue samples, known as explants, which are cultured on nutrient media to grow clones of the original plant.

Organogenesis: In this process, organs such as roots or shoots are induced directly from explants or indirectly from callus tissues. It is a crucial step for regenerating whole plants from tissue cultures. Various protocols including specific hormone treatments are optimized for different plant species to achieve successful organogenesis.

Somatic Embryogenesis: This is a method where somatic cells (non-reproductive cells) develop into entire plants through an embryo-like structure without sexual reproduction. Somatic embryogenesis is used extensively in plant breeding and genetic modification as it provides a viable path for creating genetically uniform plantlets.

Callus Culture: Callus refers to a mass of unorganized plant cells. Culturing explants in specific media induces the formation of callus tissues, which can later be differentiated into plant organs under suitable conditions. Callus cultures provide a foundation for various experimental and commercial plant tissue culture applications.

Protoplast Culture: This method involves the isolation and culture of plant cells that have had their cell walls removed (protoplasts). Protoplast culture is important for studies involving cell fusion, genetic engineering, and somatic hybridization among plants.

Applications of Plant Tissue Culture

Plant tissue culture (PTC) technology has numerous applications both in agriculture and various industries. Below, I will outline some of the prominent applications, based on recent studies and developments.

Agricultural Improvements

Crop Propagation and Improvement: PTC allows for the rapid and mass propagation of plants, particularly those that are difficult to grow through traditional methods. For instance, techniques like callus-mediated in vitro propagation and somatic embryogenesis have been optimized for crops like Sorghum, which is challenging to manipulate using conventional methods.

Disease-Free Plantlets: It facilitates the production of disease-free planting material, which is crucial in crops susceptible to seed-borne diseases. The use of tissue culture ensures healthier plantlets, leading to better yields and quality.

Biotechnology Advancements:

Genetic Modification and Transformation: PTC serves as a foundational tool in genetic engineering and transformation studies. The development of robust protocols for species like Eucalyptus enables the creation of genetically modified plants that can respond to specific agricultural and environmental challenges.

Haploid Production and Plant Breeding: Anther culture, a specialized technique within PTC, is extensively used for the production of haploids. These haploids are utilized in breeding programs to create homozygous lines more efficiently, accelerating the development of new crop varieties.

Industrial Applications:

Development of Novel Crop Varieties: Through tissue culture, new plant phenotypes with desired traits such as modified oil compositions are developed. This is particularly beneficial for industries that require plant oils with specific fatty acid profiles for food and industrial applications.

Secondary Metabolite Production: PTC enables in vitro production of secondary metabolites, essential for pharmaceuticals and nutraceuticals. For example, tissue culture of Hemidesmus indicus allows for the production of important compounds like vanillin and lupeol, which have significant therapeutic applications.

Ecological and Conservation Efforts

Conservation of Rare Species: By using tissue culture, rare and endangered plant species can be propagated and conserved in vitro without depleting their natural populations. This conservation strategy supports biodiversity and ecosystem preservation (Sharma *et al*., 2023).

Organic and Sustainable Agriculture

Enhanced Crop Quality and Yield: In organic farming, the integration of PTC with mycorrhiza applications has demonstrated improved phyto-chemical concentrations and antioxidant capacities in crops like ginger, enhancing their health-protective potential and market value.

Advantages

Season Independence: Plant tissue culture allows year-round plant production, as it is not affected by seasonal changes. This continuous production ensures a consistent supply of plants or plant compounds, which is particularly beneficial for industries like food, cosmetics, and pharmaceuticals.

High Phytosanitary Quality: The technique enables the production of plants with high phytosanitary quality, reducing the risks of disease and contamination. This is critical for maintaining plant health, especially in commercial propagation settings.

Genetic Uniformity: The practice generally maintains genetic uniformity, minimizing chemical variability that might compromise the safety and efficacy of the derived products.

Clonal Propagation: It facilitates clonal multiplication of plants, making it possible to preserve specific genotypes and produce a large number of uniform plantlets, essential for conservation and exploitation of selected or endangered genotypes.

Photoautotrophic Micropropagation System (PAM): This method enhances plant physiological processes, including photosynthesis and transpiration, by using sugar-free medium and allowing for better aeration, which improves plant vigour and health. This system is economical, efficient and can be scaled up for commercial processes.

Limitations

Contamination Risks: Contamination is a significant challenge in plant tissue culture, potentially affecting the yield and quality of the cultured plants. Ensuring aseptic conditions is critical but can be challenging in large-scale operations.

Low Culture Yield: The technique often suffers from low production yields, which makes large-scale production less viable economically. Many research strategies are being explored to enhance culture yield, but effective solutions are yet to be fully realized.

High Production Costs: The equipment, skilled labor, and controlled conditions required for plant tissue culture are costly, posing a limitation for its widespread adoption, especially in resource-constrained settings.

Limited Application in Some Species: Although tissue culture is effective in many species, some plants, particularly woody and slow-growing species, pose challenges for in vitro culture and regeneration due to their recalcitrant nature.

Technical and Infrastructure Challenges: In some regions, there is a lack of infrastructure and skilled personnel to effectively carry out tissue culture research and development, which can hinder its application in various sectors.

References

Brar, D. S., and Khush, G. S. (2021). Cell and tissue culture for plant improvement. In Mechanisms of Plant Growth and Improved Productivity Modern Approaches (pp. 229-278). CRC Press.

Soumare, A., Diédhiou, A. G., Arora, N. K., Tawfeeq Al-Ani, L. K., Ngom, M., Fall, S., ... and Sy, M. O. (2021). Potential role and utilization of plant growth promoting microbes in plant tissue culture. *Frontiers in Microbiology*, 12: 649878.

Pasternak, T. P. and Steinmacher, D. (2024). Plant growth regulation in cell and tissue culture *in vitro*. *Plants*, 13(2): 327.

Polivanova, O. B. and Bedarev, V. A. (2022). Hyperhydricity in plant tissue culture. *Plants*, 11.

Ahloowalia, B. S., Prakash, J., Savangikar, V. A. and Savangikar, C. (2004). Plant tissue culture. Low-cost options for tissue culture technology in developing countries. *International Atomic Energy Agency*, *Vienna*, 3-11.

Razdan, M. K. (2002). An introduction to plant tissue culture. Oxford and IBH publishing.

Seed Priming Techniques for Enhanced Germination

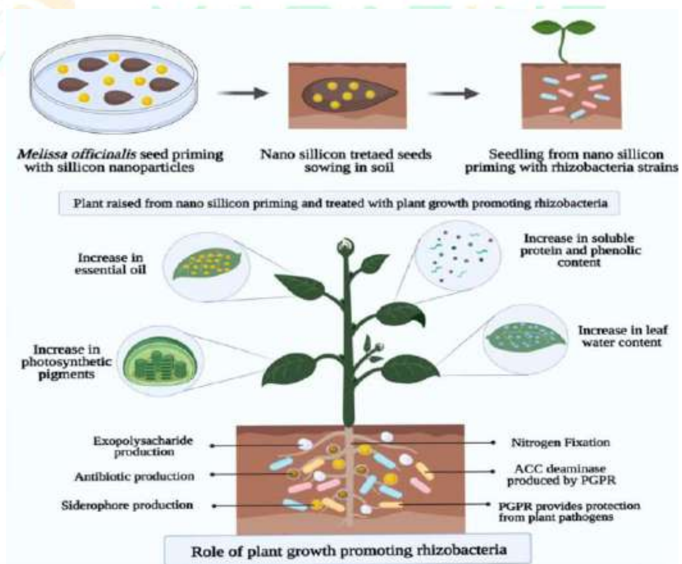
J. S. Asleen Veronika, S. Subhashini and K. Chozhan

Abstract

Seed priming is an effective pre-sowing technique that enhances seed performance by initiating controlled hydration, which activates early metabolic processes without allowing radicle emergence. This simple and eco-friendly method has gained significant importance in modern agriculture due to its ability to improve germination rate, seedling vigor, and crop establishment, especially under sub-optimal conditions. Different priming methods such as hydropriming, osmopriming, halopriming, hormonal priming, nutripriming, biopriming, and solid matrix priming have been widely adopted depending on crop type and environmental conditions. Physiologically, priming facilitates enzyme activation, repair of cellular membranes, and mobilization of stored food reserves, leading to faster and more uniform germination. Biochemical changes such as enhanced antioxidant activity and stress-related signaling further strengthen tolerance against abiotic stresses like drought, salinity, and temperature fluctuations.

Introduction

Seed germination and uniform crop establishment are critical for achieving higher productivity in agriculture. However, factors such as poor seed quality, unfavorable soil conditions, and abiotic stresses often limit successful germination. Seed priming, a pre-sowing physiological treatment involving controlled hydration, has emerged as a simple, cost-effective, and eco-friendly approach to overcome these challenges. It enhances metabolic readiness, accelerates germination, improves seedling vigor, and strengthens tolerance against environmental stresses. With diverse techniques such as hydropriming, osmopriming, and bioprim-ing, seed priming plays a significant role in sustainable crop production and ensures better yield potential.



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Types of Seed Priming Techniques

Seed priming can be performed using different approaches depending on crop species, seed physiology and field conditions. The major techniques include:

Hydropriming: Soaking seeds in water for a specific duration to initiate metabolic activities, followed by drying before sowing. It is simple, inexpensive, and widely used.

Osmopriming: Seeds are soaked in osmotic solutions such as polyethylene glycol (PEG), mannitol, or sugars, which control water uptake and prevent overhydration. This method is effective for improving stress tolerance.

Halopriming: Involves treating seeds with salt solutions like KNO_3, NaCl, or $CaCl_2$, which enhance germination and nutrient uptake while inducing stress resilience.

Hormonal Priming: Uses plant growth regulators such as gibberellic acid (GA_3), cytokinins, or salicylic acid to promote faster germination and seedling vigor.

Nutripriming: Seeds are soaked in nutrient solutions containing essential elements like zinc, iron, or molybdenum to improve seedling nutrition and growth.

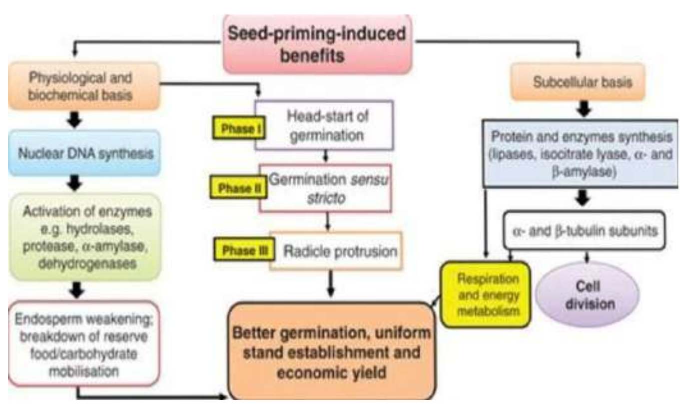
Biopriming: Incorporates beneficial microbes such as Trichoderma or plant growth-promoting rhizobacteria (PGPR), offering protection against pathogens and enhancing early vigor.

Solid Matrix Priming: Seeds are mixed with a moist carrier material (vermiculite, peat, or charcoal) that allows slow hydration under controlled conditions.

These techniques provide flexibility to farmers and researchers in optimizing germination and crop establishment.

Physiological and Biochemical Changes During Priming

Seed priming initiates several physiological and biochemical processes that prepare seeds for rapid germination. Controlled hydration reactivates metabolism, repairs damaged cell membranes, and facilitates efficient water and nutrient uptake. Enzymes such as amylase, protease, and lipase become active, leading to quicker mobilization of stored food reserves. Biochemically, priming enhances antioxidant activity, reducing oxidative damage and improving stress tolerance. DNA and protein repair mechanisms are also activated, ensuring proper cell functioning. These combined changes result in improved seed vigor, uniform germination, and better establishment under both normal and stress conditions, making priming a valuable tool in seed technology.



Benefits

- ✓ Promotes faster and uniform germination.
- ✓ Improves seedling vigor and early growth.

- ✓ Enhances tolerance to abiotic stresses (drought, salinity, temperature).
- ✓ Activates enzymes for better food reserve mobilization.
- ✓ Improves nutrient uptake and crop establishment.
- ✓ Eco-friendly and low-cost method.
- ✓ Can lead to higher yield potential.

Limitations

- ✓ Primed seeds have reduced storability (viability declines quickly).
- ✓ Over-priming may cause seed damage or abnormal germination.
- ✓ Not all crop species respond equally.
- ✓ Requires precise control of duration and conditions.
- ✓ Additional drying and handling steps needed before sowing.

Conclusion

Seed priming is an effective, low-cost technique that improves germination, seedling vigor, and stress tolerance, ensuring better crop establishment. Though reduced storability and crop-specific responses are limitations, optimized priming methods make it a promising tool for sustainable agriculture, enhancing productivity and resilience under changing environmental conditions.

References

Cañizares, E. (2025). Seeds of change: Exploring the transformative effects of seed priming on germination and seedling establishment. *Journal of Agricultural Science*, 12(3): 45-58.

Hussain, S. (2016). Physiological and biochemical mechanisms of seed priming: Enhancing stress tolerance in crops. *Frontiers in Plant Science*, 7: 1-12.

Jatana, B. S. (2024). Seed priming: Molecular and physiological mechanisms for stress resilience. *Agronomy*, 14(12): 2901.

Monajjem, S. (2023). Seed priming improves enzymatic and biochemical performances of rice seed germination under different temperatures. *Journal of Plant Growth Regulation*, 42(1): 1-10.

Rehman, Z. U. (2024). Enhancing growth and yield parameters of *Sinapis alba* through seed priming techniques. *Agronomy Journal*, 116 (4): 1234-1245.

Mechanism of Cross-Pollination

Logalakshmi, Subhashini and Cholan

Abstract

Alright, let's get into it. Plants, believe it or not, have a sex life way more dramatic than you'd expect. Sure, self-pollination is the safe, comfortable option kind of like staying home on a Friday night to binge Netflix. But cross-pollination? That's the real party. It's mixing up the gene pool, rolling the evolutionary dice, and giving plants the edge when the environment decides to throw a curveball. So, what's cross-pollination anyway? Basically, it's when pollen from one plant sneaks over to the stigma of another plant same species, but different individuals. This shuffling of DNA keeps things spicy, making sure plants don't end up with the genetic equivalent of a photocopy of a photocopy (you know, those faded, sad-looking prints). The big win? More variety. More adaptability. Survival of the weirdest and fittest. Now, plants are clever they don't just sit around hoping for a lucky gust of wind. They've evolved all sorts of tricks to make sure pollen gets where it needs to go and doesn't just end up back where it started.

Here's how they pull it off

Dichogamy - Can't Touch this: Some plants stagger the timing of their male and female bits. Like, anthers pop first (protandry think sunflowers, maize), or the stigma is ready before the pollen drops (protogyny figs, avocados). It's nature's way of saying, "Not tonight, honey. Try my neighbor."

Herkogamy - Physical Distancing, Plant Style: No chance of self-pollinating if your parts aren't even close. Flowers like hibiscus have their anthers and stigma positioned so awkwardly you'd need a contortionist bee to make it work. Spoiler: only outside help will do.

Self-Incompatibility - The Genetic Bouncer: Some plants have a built-in "no entry" policy. Their own pollen gets rejected, like a bad Tinder date. Mustard, tobacco, potatoes they're picky, and it pays off in genetic variety.

Male Sterility-Oops, No Pollen: Sometimes, plants just can't make viable pollen at all (onion, sorghum, sunflower). So, if they want to reproduce, cross-pollination is literally the only game in town. Farmers love this for making hybrid seeds.

Heterostyly i Mix it Up: Different plants in the same species have different heights for their stamens and styles, making self-pollination a logistical nightmare.

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Primulas and jasmine pull this off effortlessly.

Monoecious vs Dioecious - Who's Got What Where Monoecious: One plant, both male and female flowers, just not together (maize, castor). Dioecious: One plant, one gender, period (papaya, date palm). Gotta visit a neighbor for action.

How Does Pollen Actually Travel?

Let's talk about the real matchmakers

Wind (Anemophily): Lightweight pollen goes airborne maize, wheat, sugarcane. Basically, pollen confetti.

Water (Hydrophily): For the aquatic crowd. Pollen floats and drifts Vallisneria and Hydrilla are basically the synchronized swimmers of the plant world.

Insects (Entomophily): Showy, fragrant flowers bribe bees, butterflies and moths with nectar (sun-flowers, roses, marigolds). It's a sweet deal.

Birds (Ornithophily): Hummingbirds and sunbirds can't resist bright, tubular flowers Bombax, Bignonia.

Bats (Chiropterophily): Nightlife for real big, smelly flowers attract bats (think sausage tree, baobab).

Why Should We Care?

Genetic diversity is the real MVP. It's why we have new crop varieties, why some plants survive droughts or plagues, and why your fruit and veggies actually taste good. Cross-pollination gives us hybrid vigor (fancy way of saying "better, stronger, faster"). Plus, it keeps ecosystems balanced and resilient.

The Not-So-Glamorous Side: Look, it's not all sunshine and bees. Cross-pollination depends on outside help no bees, no birds, no wind? Tough luck. Flowers use a ton of energy to look good and smell nice for pollinators, and sometimes all that effort goes to waste if the agents don't show up.

Conclusion

So, yeah, cross-pollination is basically the plant kingdom's version of genetic speed dating. It's risky, it's wild, but it keeps things fresh. Next time you bite into a juicy hybrid fruit, just remember: somewhere, a bee worked overtime and a plant took a chance. That's nature's love story, right there. Plants have this clever trick called self-incompat-ibility basically, they block themselves from self-pollinating. It's like nature's version of "no dating your cousin," all in the name of mixing things up genetically. Wind, bugs, birds, even water these guys are the party crashers, shuttling pollen from plant to plant, keeping the gene pool nice and fresh.

In farming, cross-pollination isn't just cool it's essential. That's how we get better crops, fancy hybrid seeds, and a shot at keeping biodiversity alive instead of ending up with endless rows of flavorless tomatoes. Bottom line? Cross-pollination is nature's hack for variety, toughness, and keeping plants in the game for the long haul.

References

Faegri, K. and van der Pijl, L. (2013). Principles of Pollination Ecology. Pergamon Press.

Proctor, M., Yeo, P. and Lack, A. (1996). The Natural History of Pollination. Harper Collins.

Allard, R. W. (1999). Principles of Plant Breeding. John Wiley & Sons.

Singh, B. D. (2015). Plant Breeding: Principles and Methods. Kalyani Publishers.

Richards, A. J. (1997). Plant Breeding Systems. Chapman & Hall.

Quality Seed Production: Principles, Process and Importance in Sustainable Agriculture

Kilda R., S. Subhashini and Chozhan

Abstract

Quality seed production plays a critical role in ensuring agricultural productivity, food security, and sustainable farming. High-quality seeds ensure better germination, crop vigor, uniformity, and resistance to biotic and abiotic stresses. This article outlines the systematic approach to producing quality seeds, including site and variety selection, isolation, agronomic practices, roguing, harvesting, and storage. It also highlights the benefits of using quality seeds in enhancing crop yields and maintaining genetic purity.

Introduction

Seeds are the foundation of agriculture. The success of any crop largely depends on the quality of the seeds sown. Quality seeds contribute significantly to yield enhancement, crop resilience, and efficient input use. Hence, systematic seed production practices are essential to ensure seeds meet the required genetic, physical, physiological, and pathological standards.

Key Principles and Steps in Quality Seed Production

Site Selection: Select fertile, well-drained land with a history free of volunteer plants and diseases. Ensure reliable irrigation and favorable climatic conditions.

Variety Selection: Choose genetically pure, high-yielding, pest- and disease-resistant varieties suitable to local conditions.

Isolation Distance: Maintain appropriate distance from other similar crops to prevent genetic contamination via cross-pollination.

Land Preparation: Conduct deep plowing and fine tilth preparation to ensure good seedbed and water infiltration.

Seed Treatment: Treat seeds with fungicides or biofertilizers to prevent seed-borne diseases and enhance germination.

Sowing: Follow recommended seed rates, depth, and spacing for optimum plant population and growth.

Agronomic Practices: Apply balanced nutrients, timely irrigation and other crop management practices. Supplementary pollination may be used in

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hybrid seed production.

Roguing and Weeding: Remove off-type plants and diseased individuals to maintain genetic and physical purity.

Plant Protection: Timely use of pesticides, biocontrol agents, and integrated pest management ensures healthy seed crops.

Harvesting: Harvest at physiological maturity with optimum moisture content to preserve seed viability.

Drying and Storage: Dry seeds to safe moisture levels (typically 8-10%) and store in cool, dry, well-ventilated conditions to retain viability and vigor.

Importance of Quality Seed

Enhanced Yield: Quality seeds alone can improve yields by 15-30%.

Better Crop Establishment: Uniform germination and growth.

Efficient Input Use: Reduces fertilizer and pesticide needs.

Sustainability: Promotes resilient farming and food security.

Foundation for Hybrid Technology: Essential for hybrid seed production systems.

Conclusion

Quality seed production is not just an agricultural process but a strategic intervention to ensure productivity, profitability, and sustainability. By adopting standard procedures, maintaining genetic purity, and following scientific storage methods, farmers and seed producers can significantly enhance the effectiveness of agricultural inputs and secure future food systems.

References

Singh, B. D. (2015). Plant Breeding: Principles and Methods. Kalyani Publishers.

Agarwal, R. L. (1999). Seed Technology. Oxford & IBH Publishing.

FAO. (2010). Quality Declared Seed System. Food and Agriculture Organization of the United Nations.

Indian Council of Agricultural Research (ICAR). Manuals and Guidelines.

ISTA (International Seed Testing Association). Seed Testing Protocols.

Seed Certification

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Abstract

In general, seed certification is a process designed to maintain and make available to the general public continuous supply of high quality seeds and propagating materials of notified kinds and varieties of crops, so grown and distributed to ensure the physical identity and genetic purity. Seed certification is a legally sanctioned system for quality control of seed multiplication and production.

History of Seed Certification in India

The field evaluation of the seed crop and its certification started with the establishment of National Seeds Corporation in 1963. A legal status was given to seed certification with the enactment of first Indian Seed Act in the year 1966 and formulation of Seed Rules in 1968. The Seed Act of 1966 provided the required impetus for the establishment of official Seed Certification Agencies by the States. Maharashtra was the first State to establish an official Seed Certification Agency during 1970 as a part of the Department of Agriculture, whereas Karnataka was the first State to establish the Seed Certification Agency as an autonomous body during 1974. At present 22 States in the country have their own Seed Certification Agencies established under the Seed Act, 1966. In India, seed certification is voluntary and labelling is compulsory.

Objective of Seed Certification

The main objective of the Seed Certification is to ensure the acceptable standards of seed viability, vigour, purity and seed health. A well organized seed certification should help in accomplishing the following three primary objectives.

- ✓ The systematic increase of superior varieties;
- ✓ The identification of new varieties and their rapid increase under appropriate and generally accepted names.
- ✓ Provision for continuous supply of comparable material by careful maintenance.

Certification agency: Certification shall be conducted by the Certification Agency notified under Section 8 of the Seeds Act, 1966.

Eligibility requirements for certification

Seed of only those varieties which are notified under Section 5 of the Seeds Act, 1966 shall be eligible for certification. Any variety to become eligible for seed certification should meet the following requirement:

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General requirements

- ✓ Should be a notified variety under Section-5 of the Indian Seed Act, 1966.
- ✓ Should be in the production chain and its pedigree should be traceable.

Field standards: Field standards include the selection of site, isolation requirements, spacing, planting ratio, border rows etc.

Specific requirements: Presence of off-types in any seed crop, pollen-shedders in Sorghum, Bajra, Sunflower etc., Shedding tassels in maize crosses, disease affected plants, objectionable weed plants etc., should be within the maximum permissible levels for certification.

Seed standards: Minimum seed certification standards have been evolved crop-wise.

Process followed in Seed certification

An Administrative check on the origin of the propagating material: Source seed verification is the first step in Seed Certification Programme. Unless the seed is from approved source and of designated class certification agency will not accept the seed field for certification, thereby ensuring the use of high quality true to type seed for sowing of seed crops.

Field Inspection: Evaluation of the growing crop in the field for varietal purity, isolation of seed crop is to prevent out-cross, physical admixtures, disease dissemination and also ensure crop condition as regards to the spread of designated diseases and the presence of objectionable weed plants etc.

Sample inspection: assessing the planting value of the seeds by laboratory tests. Certification agency draws representative samples from the seeds produced under certification programme and subjects them to germination and other purity tests required for conforming to varietal purity.

Bulk Inspection: Under certification programme provision has been made for bulk inspection. Hence, the evaluation of the lot for the purpose of checking homogeneity of the bulk seed produced as compared with the standard sample is carried out. This gives an idea about the genuinity of lot and sample.

Control plot testing: Here the samples drawn from the source and final seed produced are grown side by side along with the standard samples of the variety in question. By comparison it can be determined whether the varietal purity and health of the produced seed are equal to the results based on field inspection.

Grow-out test: Evaluation of the seeds for their genuineness to species or varieties or seed borne infection. Here the samples drawn from the lots are grown in the field along with the standard checks. Growing plants are observed for the varietal purity. Grow-out test helps in the elimination of the sub-standard seed lots.

Phases of Seed Certification

Seed Certification is carried out in six broad phases listed as under:

- ✓ Receipt and scrutiny of application.
- ✓ Verification of seed source, class and other requirements of the seed used for raising the seed crop.
- ✓ Inspection of the seed crop in the field to verify

its conformity to the prescribed field standards.

- ✓ Supervision at post-harvest stages including processing and packing.
- ✓ Drawing of samples and arranging for analysis to verify conformity to the seed standards; and
- ✓ Grant of certificate, issue of certification tags, labelling, sealing etc.

Validity Period of the Certificate

The validity period shall be nine months from the date of test at the time of initial certification. The validity period could be further extended for six months provided on retesting seed conforms to the prescribed standards in respect of physical purity, germination and insect damage for all seeds except vegetatively propagating material for which lot shall be re-examined for seed standards specified for respective crop. A seed lot will be eligible for extension of the validity period as long as it conforms to the prescribed standards.

References

Mori, R. B. and Barad, A. V. Role of Seed Certification in Quality Assurance. *Seed Science & Technology*, 172.

Cowan, J. R. (1972). Seed certification. In Insects, and Seed Collection, Storage, Testing, and Certification (pp. 371-397). Academic Press.

Copeland, L. O. and McDonald, M. B. (2001). Seed certification. In Principles of Seed Science and Technology (pp. 277-295). Boston, MA: Springer US.

Seed Viability and Vigor Testing Methods

S. Asith, S. Subhashini and K. Chozhan

Abstract

Seed viability and vigor are critical parameters of seed quality. Viability indicates whether a seed is alive, whereas vigor reflects its performance potential under diverse environmental conditions. Accurate assessment through germination, Tetrazolium, accelerated aging, and electrical conductivity tests ensures high-quality planting material, uniform crop establishment, and optimized yield.

Introduction

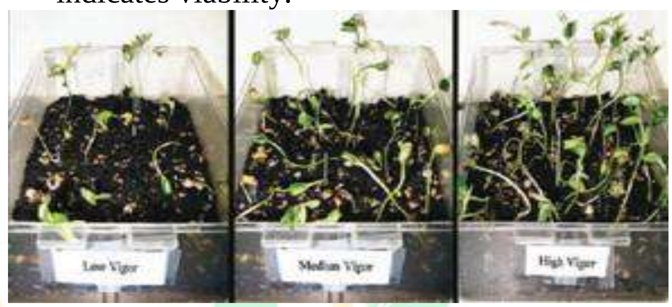
Seed quality determines crop productivity and sustainability. Viability measures the capacity of seeds to germinate and produce normal seedlings, while vigor assesses the potential of viable seeds to perform under environmental stress. Testing these parameters allows seed producers, certification agencies, and farmers to predict field performance, ensure uniform germination, and select robust seed lots. Modern approaches, including biochemical markers and image analysis, complement classical methods, enhancing accuracy and reliability in seed evaluation.

Seed Viability Testing: To determine if seeds are alive and capable of germination.

Methods

Germination Test

- ✓ Seeds are incubated under optimal moisture,
- ✓ Temperature, and light; percentage germination indicates viability.



Tetrazolium Test (TZ): Stains living tissues red, indicating metabolic activity.

Excised Embryo Test: Embryos are cultured to rapidly check viability.

Floatation Test: Non-viable seeds float due to low density. Viability testing provides essential information on seed health, helps in storage decisions, and prevents the use of dead seeds in agriculture.

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Seed Vigor Testing: To assess the performance potential of viable seeds under field stress.

Methods

Standard Germination with First Count: Early germination reflects high vigor.

Seedling Growth Measurement: Root/shoot length and dry weight indicate vigor.

Accelerated Ageing Test: Seeds exposed to high temperature and humidity; post-treatment germination reflects storability.

Electrical Conductivity Test: Measures electrolyte leakage; higher leakage indicates low vigor.

Cold Test: Germination under low temperatures simulates field stress.

Speed of Germination

- ✓ Rapid germination correlates with higher vigor.
- ✓ Vigor tests are vital for predicting field emergence and crop uniformity.

Conclusion

Assessing seed viability and vigor ensures high-quality planting material, uniform field emergence, and improved crop yields. Integration of classical and modern methods provides reliable, rapid, and precise evaluation. Routine testing is essential for seed certification, storage management, and agricultural productivity.

References

ISTA (International Seed Testing Association) Rules. (2022).

Copeland, L. O. and McDonald. (2001). Principles of Seed Science and Technology.

Ferguson, J. (1990): Report of seed vigor subcommittee. *Journal of Seed Technology*, 14: 182-184.

Association of Official Seed Analysts [AOSA]. (1983). Seed Vigor Testing Handbook. AOSA, Ithaca, NY, USA. (Contribution to the Handbook on Seed Testing, 32).

Transgenic Seeds

S. Ruba Dharsini, S. Subhashini and K. Chozhan

Abstract

Transgenic seeds, commonly known as genetically modified (GM) seeds, are developed by introducing specific genes from other organisms into crop plants to improve their traits. These seeds offer several advantages such as resistance to pests and diseases, tolerance to herbicides and environmental stresses, and enhanced nutritional value. Examples include *Bt* cotton, herbicide-tolerant soybean, and Golden rice. They have revolutionized modern agriculture by increasing crop productivity and reducing chemical usage. However, transgenic seeds also raise concerns related to biodiversity loss, environmental safety, farmer dependence on seed companies, and ethical issues. Despite these challenges, they play a vital role in ensuring food security and sustainable agriculture in the future.

Introduction

Agriculture has always been the backbone of human civilization, but in today's world, farmers face increasing challenges such as pest attacks, weed growth, unpredictable climate, and the need to produce more food for a growing population. Traditional farming methods and conventional seeds are often not enough to overcome these problems. This is where transgenic seeds, also called genetic-ally modified (GM) seeds, come into play. Transgenic seeds are created through biotechnology by transferring useful genes from one organism into another to give crops special traits like pest resistance, herbicide tolerance, drought resistance, or even higher nutritional value. For instance, *Bt* cotton protects itself from bollworm pests, and Golden rice contains vitamin A to fight malnutrition. These seeds are considered a modern agricultural innovation that can boost productivity, reduce chemical use, and support food security. However, they also bring debates on safety, cost, and environmental impacts.

Transgenic Seeds: Transgenic seeds, also known as genetically modified (GM) seeds, have been engineered to possess desirable traits such as resistance to pests, diseases, or herbicides, as well as enhanced yield potential and nutritional content.

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Here are some key points and popular articles related to transgenic seeds.Transgenic seeds are created by transferring a gene from one organism (bacteria, plant, or even animal) into a crop plant's DNA. This new gene, called a transgene, gives the crop a special trait it did not have before. For example:

- ✓ Bt cotton resists bollworm pests using a bacterial protein.
- ✓ Herbicide-tolerant soybean allows farmers to control weeds without harming the crop.
- ✓ Golden rice is enriched with vitamin A to fight malnutrition.

Benefits of Transgenic Seeds

Increased Crop Yield: Transgenic seeds can improve crop yields, reducing the need for land expansion and deforestation.

Pest and Disease Resistance: Traits like insect resistance and disease resistance can minimize crop losses and reduce pesticide use.

Herbicide Tolerance: Allows crops to withstand specific herbicides, simplifying weed management.

Improved Nutrition: Scientists can enhance the nutritional content of crops, addressing micro-nutrient deficiencies.

Types of Transgenic Seeds

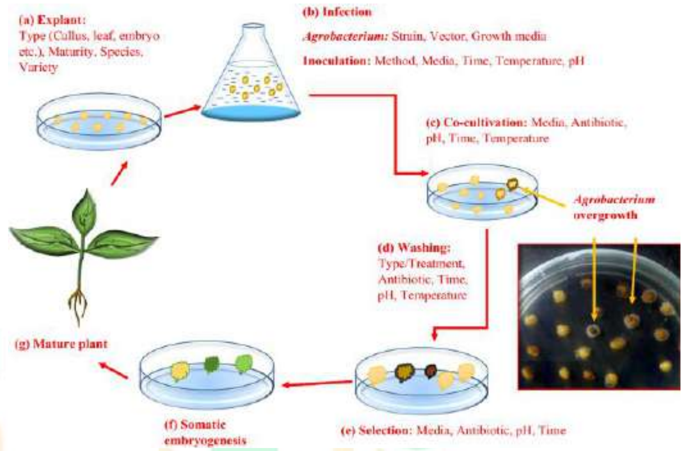
Herbicide-Tolerant Seeds: Engineered to withstand specific herbicides, reducing weed competition.

Insect-Resistant Seeds: Produce proteins toxic to certain pests, minimizing damage.

Drought-Tolerant Seeds: Designed to thrive in water-scarce conditions.

Market Trends and Growth

- ✓ The global transgenic seeds market is expected to grow at a CAGR of 12.2-13.1% from 2024 to 2030/2034, driven by increasing demand for food security and sustainable agriculture.
- ✓ North America dominates the market, while Asia-Pacific is projected to experience signific-ant growth.



Examples of Transgenic Crops

Corn: Engineered for traits like insect resistance, herbicide tolerance, and improved nutritional content.

Soybean: Modified for herbicide tolerance and insect resistance.

Cotton: Designed for insect resistance and herbicide tolerance.

Canola: Engineered for improved oil quality and herbicide tolerance.

Importance

Boost productivity: Farmers harvest more from the same land.

Less pesticide use: Built-in pest resistance reduces chemical spraying.

Stress tolerance: Some seeds tolerate drought, salinity, or poor soils.

Better nutrition: Biofortified crops fight hidden hunger.

Sustainable farming: Reduces pressure on land and resources.

The Other Side of the Story

Despite their benefits, transgenic seeds spark debates:

- ✓ High prices make farmers dependent on seed companies.
- ✓ Pests and weeds may eventually become resistant.
- ✓ Concerns exist about environmental safety and biodiversity.
- ✓ Ethical issues about "tampering with nature."

Conclusion

Transgenic seeds represent a bold step in humanity's quest for food security. They hold the power to feed a growing population and reduce farming hardships. Yet, careful regulation, farmer education, and long-term safety checks are essential to balance benefits with risks. The future of farming may well be written in the genes of these tiny but powerful seeds.

References

Zhong, G. Y., Peterson, D., Delaney, D. E., Bailey, M., Witcher, D. R., Register Iii, J. C., ... and Howard, J. A. (1999). Commercial production of aprotinin in transgenic maize seeds. *Molecular Breeding*, 5(4): 345-356.

Kinchy, A. (2012). Seeds, science, and struggle: The global politics of transgenic crops. MIT press.

Prieto-Dapena, P., Castano, R., Almoguera, C. and Jordano, J. (2006). Improved resistance to controlled deterioration in transgenic seeds. *Plant physiology*, 142(3): 1102-1112.

Rani, S. J. and Usha, R. (2013). Transgenic plants: Types, benefits, public concerns and future. *Journal of Pharmacy Research*, 6(8): 879-883.

Insect Insights: Understanding Climate Change Impacts

Anushka S. R. and Santhoshkumar T.

Abstract

Climate change is influencing insect population in complex ways, with both positive and negative implications for agriculture and ecosystems. Rising temperature, shifts in precipitation and extreme weather events are altering insect life cycles, distribution patterns, and interactions with crops and natural enemies. These changes have contributed to increased pest outbreaks, reduced effectiveness of traditional pest control methods and disruptions in pollination and biological control, threatening crop yields and food security. Adapting to these changes requires integrated approaches including climate-resilient pest management, habitat restoration, farmer education, and advanced tools like Geographic Information Systems (GIS) for monitoring and forecasting pest dynamics. Understanding the impacts on insects is essential for developing sustainable and adaptive agricultural strategies in a changing climate.

Introduction

Climate change greatly affects insect population and their distribution as insects can quickly adapt due to their short life cycle and high reproduction. These rapid changes can impact crop protection and food security, especially in developing countries. Therefore, future pest management strategies must consider climate change to stay ahead of pest adaptations (Sharma, 2010). On the other hand conserving beneficial insects are also important for better pollination.

Effect of temperature: As global temperature rise, insects, the key players in ecosystem are undergoing dramatic changes in their abundance, distribution and behavior. Warmer conditions allow pest species to thrive, reproduce faster and expand their range into new areas, particularly in cooler regions where they previously struggled to survive. Some insects, unable to escape rising temperatures moves to uphill or poleward and may face extinction. These shifts are altering food webs and impacting insect biodiversity which is a vital indicator of ecosystem health. Temperature changes also disturbs the natural timing of insect life cycles. Insects are maturing and reproducing earlier, causing potential mismatches with their host plants or natural enemies. For example, some butterflies emerge when their host plants are no longer available, leading to population decline. Rising temperature disrupt insect survival tactics like overwintering causing them to emerge earlier resulting in more generations per year. This boosts pest populations, particularly in warmer

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regions, resulting in more frequent and severe outbreaks. Heat stress, including warmer nights also affect insect fertility, survival and interactions with other species. Beyond temperature, other climate-related factors like drought and fire are reshaping insect population. Drought can reduce food availability for herbivorous insects, especially those feeding on small plants, while increased damage to trees from wood-boring insects. Changes in plant quality under stress also affect pollinators. Wildfire become more frequent with climate change and have mixed effects: they destroy habitats for some insects but create opportunities for others, often benefiting generalist pests. Aquatic insects, which spend part of their lives in water, are particularly vulnerable to rising temperatures and drought due to oxygen limitations and mobility constraints.

Effect of precipitation: Distribution and frequency of rainfall may affect the incidence of pests directly as well as through changes in humidity levels. Heavy rains may suppress sucking pests like aphids, thrips, whiteflies and leafhoppers, but can trigger outbreaks of others such as red hairy caterpillars and cutworms, particularly after dry spells. Some species, like *Agriotes lineatus* larvae, thrive under increased rainfall, while others, such as *Lecanopsis formicarum* show little change. Flooding can directly displace insects and indirectly affect them by altering soil conditions -reducing oxygen levels and changing pH, which impacts soil-dwelling species. Wet soil can also drive these insects to the surface, exposing them to predators. While some insects have evolved flood-avoidance behaviors, such adaptations are often limited to regions where rainfall reliably signals upcoming floods.

Effect of increased CO_2: Elevated CO_2 levels can reduce the nutritional quality of host plants, particularly by lowering leaf nitrogen content and increasing the carbon-to-nitrogen (C:N) ratio due to higher levels of non-structural carbohydrates. According to the "nutrition compensation hypothesis," herbivorous insects, especially lepidopterans, compensate for this nutrient imbalance by increasing their feeding to meet nitrogen and amino acid needs, a behavior known as compensatory feeding (Lincolin *et al.,* 1993). This altered plant chemistry negatively affects insect development, leading to longer larval and pupal stages, reduced pupation rates, lower pupal weight, and decreased growth and food conversion efficiency. In contrast, sap-feeding insects like hemipterans are less impacted. Elevated CO_2 also boosts plant defensive compounds like phenols, tannins, and flavonoids, while reducing nitrogen-based metabolites and terpenoids, further influencing insect performance.

Effect of climate change on Natural enemies: Climate change can directly impact the biology and behavior of natural enemies and their prey, potentially reducing the effectiveness of biological control. Optimal predator and parasitoid activity typically occurs around 24-26 °C, and temperature beyond this range may hinder their performance. Elevated CO_2 may favor generalist natural enemies over specialists. Additionally, climate change can disturb the timing (synchrony) between pests and their natural enemies, which is crucial for successful biological control. Mismatches in timing can reduce control efficiency and may even lead to natural enemy mortality.

Effect of climate change on pest management: Climate change is disrupting pest management by reducing the effectiveness of key strategies such as host plant resistance, biological control and chemical pesticides. Higher temperature, increased UV radiation and lower humidity affect insect behavior and plant health, leading to earlier pest outbreaks and reduced control by natural enemies due to disrupted synchrony. Natural enemies are sensitive to climate changes; while some predators may perform better at moderate temperatures, extreme heat can reduce their reproduction and survival. Synthetic insecticides show mixed responses, some become more effective with rising temperatures, while others degrade faster. This increase costs and risk of resistance, pest resurgence and secondary pest outbreaks, highlighting the urgent need for more adaptive and integrated pest management strategies.

Management Strategies for Insect Resilience to Climate Change: Climatic factors such as temperature and water availability significantly influence key stages in a plant's life cycle, including flowering, pollination, and fruit development (Cleland *et al*., 2007). Both the quality and quantity of pollination play a vital role in ensuring food security, maintaining species diversity, supporting ecosystem stability and enhancing resilience to climate change (FAO, 2008). To help insects cope with climate change, management efforts should focus on both broad landscapes and smaller microhabitats. Insect communities that are diverse and structurally complex, with a variety of plant species, create microclimates that serve as natural refuges during extreme weather. Features like hedgerows, flower strips and woodlots act as buffers by reducing wind and temperature fluctuations, providing shelter for beneficial insects. In mountainous regions, cold-adapted species find refuge in rocky areas such as glaciers and ice-covered landforms. Identifying and protecting these refuges is essential for conserving insect diversity. Moving from conventional farming to agroecological practices increases landscape complexity, boosting insect resilience and supporting ecosystem services like pest control. For aquatic insects, maintaining good water quality and flow helps prevent oxygen loss, reducing heat stress. Reducing pesticide use and increasing shading or groundwater retention further mitigate warming effects. Creating a mosaic of habitats with varied temperatures offer insects temporary shelter from heat extremes. Controlled burns, when limited in scope, can promote habitat diversity and allow insect population to recover quickly. Overall, managing insect habitats effectively requires considering the combined impact of climate change and other human activities to build resilient ecosystems.

Conclusion

Climate change is significantly affecting insect behavior, distribution and population dynamics, leading to increased pest outbreaks and crop losses. To build resilience, it is essential to restore insect-friendly habitats and adapt pest management strategies. This includes raising awareness among farmers, adjusting crop calendars, breeding stress-tolerant crop varieties and using traditional practices like natural mulching. Tools like GIS can help predict pest outbreaks and identify high-risk areas, supporting more effective, area-wide management. Recent studies indicate that certain insecticides may have a dual benefit, enhancing plant stress tolerance and offering new avenues for research and integrated pest management strategies in the context of climate change.

References

Sharma, H. C. (2010). Global warming and climate change: Impact on arthropod biodiversity, pest management, and food security. In: Thakur, R., Gupta, P. R. and Verma, A. K. (eds.), *Perspectives and Challenges of Integrated Pest Management for Sustainable Agriculture*, Souven Natn Symp Nauni, Solan, Himachal Pradesh, pp.1-14.

Cleland, E. E., Chuine, I., Menzel, A., Mooney, H. A. and Schwartz, M. D. (2007). Shifting plant phenology in response to global change. *Trends in Ecology and Evolution*, 22(7): 357-365.

FAO [Food and Agriculture Organization] (2008). Rapid Assessment of Pollinators Status [online]. Available: https://www.fao.org [24 July 2025].

Lincoln, D. E., Fajer, E. D., and Johnson, R. H. (1993). Plant-insect herbivore interactions in elevated CO_2 environments. *Trends in Ecology and Evolution*, 8(2): 64-68.

Women in Agriculture: Strengthening Food Security through Innovation

Joe Shiney M. A. and Megha A. M.

Abstract

Women form the backbone of agriculture and play a central role in ensuring food and nutritional security. Despite contributing nearly half of the global agricultural workforce, women face structural barriers such as limited land ownership, credit access, and recognition as farmers. This article highlights women's roles as custodians of seeds, nutrition managers, and innovators, and explores how climate-smart practices, digital inclusion, agroecology, and women-led collectives are strengthening food security. Drawing upon recent research and case studies from India and beyond, it emphasizes that closing gender gaps in agriculture is not only a matter of equity but also a prerequisite for sustainable food systems.

Introduction

Agriculture continues to sustain rural livelihoods, with women playing a critical role as cultivators, food processors, and nutrition providers. In South Asia, women contribute substantially to agricultural labour yet remain marginalized in land rights, decision-making, and access to modern technologies (Islam *et al.*, 2024). Globally, gender inequalities in agriculture cost nearly US$1 trillion annually, and bridging these disparities could raise farm yields by 20 to30%, potentially reducing the number of food-insecure people by 45 million (FAO, 2023). This makes empowering women in agriculture not just a social justice issue but also a powerful tool to strengthen food and nutrition security.

Women as Custodians of Food Security: Women ensure the four pillars of food security, availability, access, utilization, and stability. Their contribution goes beyond fieldwork to seed conservation, household dietary planning, and livestock care. Studies show that women's empowerment in agriculture directly improves household resilience and nutrition outcomes (Gupta, 2023). Recent findings reinforce this. For example, women's participation in livestock management enhances child nutrition outcomes (Hira *et al.*, 2025). Similarly, decision-making power combined with farm production diversity significantly improves dietary diversity (Mohammed *et al.*, 2025).

Innovation as a Catalyst

Agricultural innovation is increasingly reshaping women's role as farmers and entrepreneurs:

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Climate-Smart and Agroecological Practices: Women farmers are adopting organic farming, natural resource management, and integrated pest control to cope with climate stress. Case studies from Himachal Pradesh highlight how agroecology enhances women's autonomy and decision-making. (Hossain *et al*., 2024)

Digital Tools and Inclusion: Mobile-based applications, WhatsApp advisory groups, and farmer helplines are bridging information gaps. Recent studies emphasize that digital inclusion is emerging as a pathway to sustainable agriculture for women in India (Dutta, 2025). Similarly, digital innovations in smart agriculture are enabling women to access real-time data, improving resource efficiency (Balyan *et al.*, 2024).

Community Collectives and Seed Innovation: Women-led self-help groups and community institutions play a vital role in adopting new seed varieties. In Uttar Pradesh, SHGs facilitated access to improved seeds, boosting productivity and resilience (Balyan *et al.*, 2024).

Women, Innovation, Nutrition and Economic Empowerment: Innovations in agriculture not only improve yields but also enhance women's economic empowerment. Women-led enterprises in organic produce, value-added food processing, and seed banks are creating sustainable livelihoods while supporting local food systems. Empowering women to become agri-entrepreneurs has shown multiplier effects; raising incomes, improving family nutrition, and reducing rural poverty.

Nutrition-sensitive agriculture relies heavily on women's leadership. A systematic review of women's participation shows improvements in dietary diversity and income, especially when paired with reduced workload and increased decision-making power (Gupta, 2025). This is supported by new evidence: farm households where women actively participate in agricultural decisions record better nutritional outcomes, highlighting the dual role of women as both producers and nutrition managers (Mohammed *et al.*, 2025).

Women as Community Leaders in Sustainable Development: Women are increasingly recognized as leaders in sustainable agriculture movements. Their leadership in farmer producer organizations, SHGs, and climate action committees demonstrates how inclusive governance can transform rural communities. Women-led networks have been crucial in spreading agroecological practices, climate adaptation strategies, and nutrition education. Recognizing women not just as beneficiaries but as decision-makers ensures stronger, more resilient communities.

Challenges and Policy Gaps

Despite progress, challenges persist:

Land Ownership: Less than 15% of women in India hold land titles (Kaur, 2016).

Credit and Resources: Institutional bias limits access to financial services.

Recognition: Women often remain "invisible farmers" in policy frameworks.

Structural Constraints: Workload, time poverty,

Table 1: Women's Role in Agriculture, Key Barriers and Innovations Strengthening Food Security

Women's Role	Key Barriers	Innovations Strengthening Food Security
Food producers and cultivators	Limited land ownership; lower access to credit & technology	Climate-smart practices (organic farming, crop diversification, water conservation)
Seed keepers and nutrition managers	Workload, time poverty, low decision-making power	Nutrition-sensitive farming; decision-making inclusion improves dietary diversity
Livestock managers	Limited control over income & resources	Women's empowerment in livestock linked to improved child nutrition
Entrepreneurs and community leaders	Weak institutional support; lack of recognition	Women-led SHGs/FPOs; adoption of improved seed varieties
Adopters of technology	Digital divide; low ICT literacy	Mobile apps, smart agriculture, digital inclusion
Agents of sustainability	Exclusion from policy & extension services	Agroecology, natural farming, socio-technical innovations

and lack of voice in decision-making reduce their effectiveness.

A recent review highlights that smallholder viability in South Asia is undermined by policy gaps, requiring gender-sensitive interventions (Vippala and Rahut, 2025). Policy reforms must prioritize gender equality in extension services, resource allocation and climate adaptation programs. Integrating women into agricultural policy frameworks will ensure both productivity and sustainability.

Conclusion

Women farmers are not just contributors but leaders of agricultural transformation. Closing gender gaps in land rights, digital access, and innovation is crucial to strengthen food and nutrition security. As global evidence shows, empowering women can boost productivity, enhance resilience, and reduce hunger. Equally important is recognizing women as custodians of crop diversity, natural resource managers, and promoters of sustainable practices. Their traditional knowledge of seeds, soil, and water management has kept rural communities resilient for generations. By combining this wisdom with modern innovations such as digital agriculture and climate-smart technologies, women can lead the way in building food systems that are both sustainable and equitable. Women's roles extend beyond farming into community leadership, nutrition planning, and policy advocacy. Supporting women-led collectives, ensuring gender equality in agricultural policy, and investing in women's economic empowerment are transformative strategies for achieving global food security. "When women grow, the world eats better. Empowering women in agriculture is a pathway to resilient and sustainable food systems."

References

Balyan, S., Jangir, H., Tripathi, S. N., Tripathi, A., Jhang, T. and Pandey, P. (2024). Seeding a sustainable future: Navigating the digital horizon of smart agriculture. *Sustainability*, 16(2): 475.

Dutta, S. (2025). Empowering women through digital inclusion: A pathway to sustainable agriculture in India. *South Asian Journal of Agricultural Sciences*, 5(2): 110-114.

FAO. (2023). *Gender inequalities in food and agriculture are costing world $1 trillion: FAO.* UN News. https://news.un.org/en/story/2023/04/1135597

Gupta, P. (2025). A Systematic Review on Women's Participation in Agricultural Work and Nutritional Outcomes. *arXiv preprint arXiv:* 2504.03202.

Gupta, S. (2023). Impact of women's empowerment in agriculture on farm productivity and household resilience in rural Bihar.

Hira, F. T. Z., Alam, M. J. and Begum, I. A. (2025). Women's empowerment in livestock sector as a tool to enhance child's nutrition: a review. *Discover Sustainability*, 6(1): 1-13.

Hossain, M., Nayak, S., Mohapatra, S., Trivedi, P. and Waza, S. A. (2024). Women-led community institutions as a potential vehicle for the adoption of varieties and improved seed practices: an impact case from India. *CABI Agriculture and Bioscience*, 5(1): 53.

Islam, M. M., Jannat, A. and Al Rafi, D. A. (2024). Women participation in South Asian agriculture: a comprehensive systematic review. *Discover Sustainability*, 5(1): 490.

Kaur, V. (2016). The Role of Women in agriculture. *Indian Farming*, 66(1).

Mohammed, F. Y., Khonje, M. G. and Qaim, M. (2024). Women's roles in decision-making and nutrition-sensitive agriculture.

Vippala, R. R. and Rahut, D. B. (2025). Smallholder viability and food security in South Asia: constraints and policy options. *Frontiers in Sustainable Food Systems*, 9: 1657409.

Enzymes and Crossing Over

Amirtha Preetham, S. Subashini and Cholan

Abstract

Linkage is the tendency for genes located on the same chromosome to be inherited together. In contrast, crossing over is a process during meiosis where homologous chromosomes exchange segments of genetic material, creating new combinations of genes and increasing genetic variation. While linkage preserves parental traits, crossing over disrupts these linked genes to produce new, recombinant traits.

Introduction

In eukaryotic organisms, linkage and crossing over are two related but distinct events. The tendency of genes to stay together on a chromosome is known as genetic linkage while crossing over is a phenomenon in which genetic information is exchanged in the germline. Both these factors have a significant impact on heredity. And both are connected in some way. Linkage, on the other hand, refers to the tendency of genes on a chromosome to be inherited together. The genes separate and segregate into various gametes as a result of crossing over. Here, we'll learn more about genetic linkage and crossing-over definitions as well as the differences between the two.

Genetic linkage

Genetic linkage, as previously stated, relates to the possibility of genes or DNA sequences in a chromosome being inherited together during meiosis stage of sexual reproduction. The genes that are linked are those that are found on the same chromosome. For example, take the genes that influence hair and eye colour. That is why some people have the same hair and eye colour. For example, you can consider those with black hair and brown eyes, inherited from their parents, or people with brown hair and blue eyes inherited from their parents.

Significance

Linkage prevents breeders from combining attractive traits into a single variety. In genetics, a linkage group is made of all the genes on a dedicated chromosome. They are acquired as a unit, which means they work and move as a unit throughout cell division, rather than independently of the existence of linkage groups, some features do not follow Mendel's law of independent assortment (recombination of genes and the traits they govern), which

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states that the principle only applies if genes are on different chromosomes. When the chromosome breaks and the sections reunite with the companion chromosome, if it has broken in the same places, the gene content of the chromosome can change. Crossing over refers to the transfer of genes between chromosomes.

Crossing over

Cross over occurs when non-sister chromatids swap chromosomes to create gametes. Crossing over shuffles the alleles on parental chromosomes, resulting in gametes that carry a mix of mother and father's DNA. In layman's terms, it's the exchange of genetic material in the germline. Pairs of chromosomes align during meiosis or the creation of egg cells and sperm cells so that similar DNA sequences from the paired chromosomes come up against one another. This mechanism is responsible for genetic variation in sexually reproducing organisms and is also required for correct chromosome segregation.

Mechanism of crossing over

Here are the linkage and crossing over classifications:

Synapsis: The maternal and paternal homologous chromosomes move close to each other and begin pairing along their lengths during the zygotene substage of prophase I. Synapsis is the joining of homologous chromosomes. Bivalents are homologous chromosomes that have been coupled. Crossing over is based on mechanical principles.

Duplication of Chromosomes: The synapsis is preceded by chromosome duplication. The chromatids of each homologous chromosome divide lengthwise and create two identical sister chromatids during the pachytene substage of prophase I. Tetrad refers to the fact that each bivalent includes four chromatids.

Crossing Over: At one or more locations, the non-sister chromatids of a homologous pair twist over each other. Due to the action of the enzyme, the chromatid segments split at the relevant locations, and the segment of one side merges with the segment of the opposing side. As a result, chromatid segment breakage, transposition, and fusion are all part of the crossing over process.

Chiasmata Formation: Chiasmata are the places where two homologous chromosomes join and cross across. The number of chiasmata is proportional to the length of the chromosomes; the longer the chromosomes, the higher is the number of chiasmata. Crossing over can occur at one or more points in a tetrad, resulting in the production of one or more chiasmas.

Terminalisation: The non-sister chromatids begin to resist each other after crossing over due to a lack of attraction force between them. The chromatids are repelled from the centromere to the chiasma, and the chiasma itself travels in a zipper pattern towards the tetrad's end. Terminalisation is the migration of the chiasma, and the homologs are entirely separated due to terminalisation.

Difference

- ✓ The process of separating genes across homologous pairings into distinct gametes is known as crossing over. The tendency to inherit genes on the same chromosome is known as linkage.

- ✓ When two genes on the same chromosome are closer to each other, this is known as linkage. Crossing over, on the other hand, occurs when two genes on the same chromosome are far apart.
- ✓ Crossing over may cause the gene groups formed via linkage to be disrupted.
- ✓ Crossing over occurs exclusively during the prophase of meiosis I, unlike the linkage, and it results in recombinant alleles, which is not the case in linkage.

Characteristics of crossing over

Genes that show linkage are situated in the same Chromosome.Genes are arranged in a linear fashion in the chromosome i.e., linkage of genes is linear.The distance between the linked genes is inversely Proportional to the strength of linkage. The linked genes show two types of arrangement on the Chromosome (Cis and trans arrangement). Crossing over is the exchange of segments between the non-sister Chromatids of homologous chromosome. The term crossing over was coined by Morgan. It is the mutual exchange of segments of genetic material between Non-sister chromatids of two homologous chromosomes, so as to produce.

Conclusion

Hopefully, these notes will help you in comprehending the primary topics and recalling the exam's most important parts. All the genes on a chromosome are said to be linked to one another.

The process of inheritance of linked genes in the same linkage group is termed as linkage. The crossing over provides origin of new characters due to the exchange of a segment from one chromosome to another and thus it is a source of genetic variation. Whereas linkage reduces the possibility of variability in gametes unless crossing over occurs.

Seed Dormancy, Mechanisms and Breaking Techniques

M. Dhinesh Kumar, S. Subhashini and K. Chozhan

Abstract

Seed dormancy is a natural mechanism that prevents seeds from germinating even under favorable conditions. This adaptive trait helps plants survive harsh environments and time their germination for maximum success. For agricultural and horticultural purposes, however, dormancy can delay crop establishment and reduce yields. Understanding the causes of dormancy. Such as hard seed coats, immature embryos, or natural chemical inhibitors and applying proper breaking techniques like scarification, soaking, stratification, or growth-promoting chemicals ensures faster and uniform germination. By overcoming dormancy, farmers and gardeners can improve seed performance and productivity.

Introduction

Seed dormancy is like a pause button in nature. It allows seeds to rest and wait until the right environmental conditions such as suitable temperature, moisture, and light are available for germination. While this trait protects seeds in the wild, it often poses challenges in farming and gardening.

Why Seeds remain Dormant

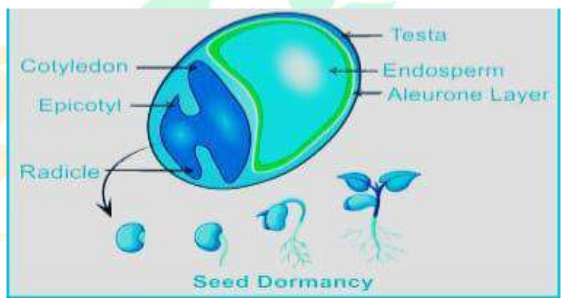
Seeds may remain dormant due to:

Hard seed coat: Prevents water and air from entering (e.g., beans, peas).

Immature embryo: Requires further development after seed harvest (e.g., ginkgo, carrot).

Natural inhibitors: Chemical compounds like abscisic acid delay germination.

Specific environmental needs: Some seeds germinate only after exposure to cold winters, dry periods, or even forest fires.



Techniques for Breaking Dormancy

To promote uniform and timely germination, several techniques:

Scarification: Scratching or softening the hard seed coat.

Soaking: Keeping seeds in water to soften their coats.

Temperature treatment: Exposing seeds to alterna-

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ting cold and warm conditions (stratification).

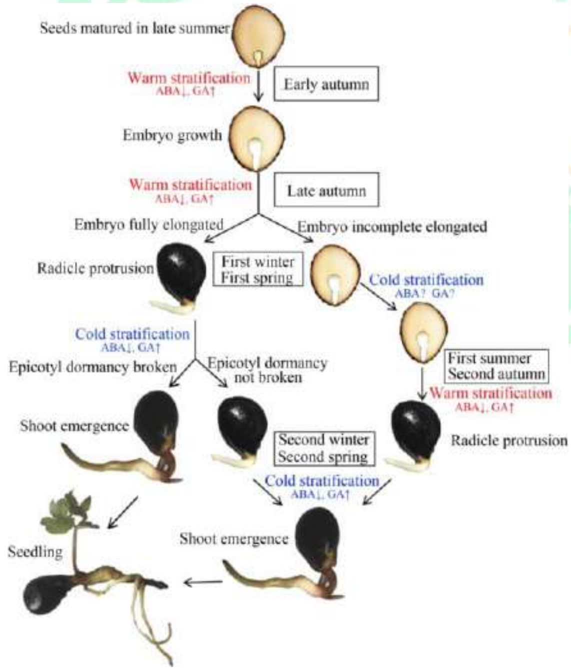
Hormonal treatment: Applying growth promoters like gibberellic acid (GA_3).

Leaching inhibitors: Washing seeds to remove chemical barriers.

Fire or smoke exposure: Common for wild species in fire-adapted habitats.

Practical Examples

- ✓ Paddy seeds are soaked before sowing to ensure quick sprouting.
- ✓ Apple and cherry seeds are exposed to cold stratification for germination.
- ✓ Gardeners chip or nick morning glory seeds to speed up germination.



Importance of Breaking Dormancy

Breaking Dormancy

- ✓ Ensures uniform field emergence.
- ✓ Improves germination percentage and crop yield.
- ✓ Aids in conservation of rare and endangered species.
- ✓ Reduces storage time and enhances agricultural productivity.

Conclusion

Seed dormancy is a remarkable natural adaptation that ensures plant survival, but it can be a barrier in agriculture and horticulture. By understanding its mechanisms and applying the right dormancy-breaking methods, farmers and gardeners can unlock a seed's full potential and support better germination and healthy plant growth.

References

Bewley, J. D., Bradford, K. J., Hilhorst, H. W. M. and Nonogaki, H. (2013). Seeds: Physiology of Development, Germination and Dormancy (3rd Ed.). Springer.

Baskin, C. C. and Baskin, J. M. (2014). Seeds: Ecology, Biogeography, and Evolution of Dormancy and Germination (2nd Ed.). Academic Press.

Copeland, L. O. and McDonald, M. B. (2001). Principles of Seed Science and Technology (4th Ed.). Springer.

Seed Pricing Policy

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Abstract

Seed pricing is a crucial determinant of agricultural productivity, seed industry sustainability, and farmer adoption of improved varieties. Pricing decisions are shaped by both public and private sector objectives, where governments focus on affordability, food security, and farmer welfare, while private companies emphasize profitability, market growth, and competitiveness. Different strategies such as low, market-based, and premium pricing are employed depending on demand sensitivity, production costs, and competition. Techniques like cost-plus, contribution, and competitive pricing further influence how seed prices are set in practice. The effectiveness of any pricing approach depends not only on economic considerations but also on technological innovation, research outputs, and supportive policy frameworks. By balancing these factors, seed pricing can serve as a driver of agricultural innovation, sustainable development, and equitable growth in the farming sector.

Seed pricing

Seed pricing involves setting prices when a new product is launched or a new distribution channel is used. Also, decisions may need to be taken to change the price in response to competition and to the general market situation. In the public sector prices are often based on an economic pricing policy. Economic pricing considers the effect of seed price on the economy, taking into account the amount officials think farmers can afford to pay and the role of the seed industry in the development of agricultural production. Ideally, however, the public sector should follow a more commercial pricing policy which accounts for all costs and allows for an element of profit.

What is price?

Price has different meanings for different groups of people:

- ✓ To the buyer price is a cost which is used as a measure of value; the buyer evaluates one variety or source of seed against the alternatives;
- ✓ To the seller price is revenue and therefore a key element in the marketing mix; setting the right price is an important tactical decision and is a key factor influencing revenue and profit;
- ✓ To a government price may mean popularity and votes and is therefore a sensitive political issue; governments may therefore seek to influence and

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control seed pricing.

The importance of price varies from one market to another and between different segments in the same market. For example, non-hybrid seed, which the farmer can save, will be more price sensitive than hybrid seed. Price will be a more critical factor in marginal farming areas, where spending power is low, but less important where high yields can be obtained and farm produce can be sold profitably. Providing the benefits of the seed are understood, it is other factors, such as the availability of fertilizer and confidence in the produce market, rather than price that dominate the farmer's decision to purchase.

Objectives

Some objectives in government seed pricing could be:

- ✓ To induce farmers to use certified seed of improved varieties in order to increasenational production.
- ✓ To provide adequate incentives to seed producers to supply seed in sufficient quantity.
- ✓ To meet demand.
- ✓ To encourage the development of private distribution channels.
- ✓ To implement government agro-economic policies.

Some objectives in private sector seed pricing are likely to be:

- ✓ Props maximization which will be the long-term target although there may be many other shorter term considerations which will influence pricing policy, such as increasing market share and gaining acceptance of new product.
- ✓ Price competition, may be achieved by setting a price that gives a competitive edge in the market place but may not be lower than that of a rival because other factors, such as service, will be contributing to a company's competitive advantage.
- ✓ An investment tha must be at least as good as other uses for investors' funds.

Pricing strategies

Once a company's seed pricing objectives have been established, different pricing strategies must be considered. These include:

Low price strategy: Low price strategies are used where consumers respond very positively to small downward changes in price, but a company may not always gain from setting low prices as more efficient competitors may respond with similar price cuts. If the product is not particularly price sensitive then the net effect of a price reduction can simply mean a reduction in revenue. A company may be tempted to reduce its price where similar or substitute products are also sold or when there is an oversupply. However, seeds can become devalued by selling them cheaply especially where there are real benefits associated with the product. Imported vegetable seeds are often chosen by farmers in preference to locally produced varieties in the belief that they are better because they are more expensive. It is therefore critically important to understand the likely response of the farmer when adopting a low price strategy.

Market price strategy: Where a few large companies dominate supply, products tend to be similar (known in the seed industry as "me-too" varieties) and the role of price tends to be neutral, i.e. a market price is established.

High price strategy: This strategy can be used as a long- or short-term policy. In the case of the long-term policy the company will have identified a market segment for a high quality, value-added product such as graded and treated seed for precision drilling. A high price will reflect the exclusive image or added value of the product. A short-term, high-price policy takes advantage of a new product introduced onto the market, as may be the case with a new high-yielding variety where supply is limited.

Pricing techniques: The important influences on pricing are cost, demand, prices of the product's main competitors and short-term sales targets.

Cost-plus pricing: This method involves calculating the unit cost of a product and adding the appropriate profit margin to give a base price which might then be altered in relation to prevailing market conditions. While this seems a simple approach the fact that such pricing is production oriented and may therefore not reflect what is happening in the market place, makes it risky. A rigid application of cost-plus pricing may lead to price increases when demand is lower and reductions when demand is strong. This is the opposite of what should normally be done.

Contribution pricing: This is a form of cost-plus pricing which involves separating the different products that make up the product portfolio and allocating to them the direct costs associated with their production. The price is determined at a level which will generate revenues in excess of these costs, thereby contributing towards meeting business overheads. Individual products can be analysed in terms of their ability to cover their direct costs and contribute to overheads.

Competitive pricing: Where there is market competition, costs cannot always be the determining factor in pricing. Here the nature and extent of competition will have a major influence on the price. If a product is faced with direct competition from similar products the price will be restrained. In contrast, when a product is faced by indirect competition from products in different sectors of the market there will be more scope to vary the price. This provides the possibility of using different strategies.

Short-term pricing techniques: Pricing can be a useful tool for pursuing short-term marketing and sales targets. When a new variety is launched higher prices can be set, providing the opportunity of earning higher returns from those farmers willing to pay the higher prices before seed becomes more widely available. Lower prices may be linked to promotional activities such as boosting sales of established varieties, creating interest in new ones, reducing high stocks and encouraging farmers to buy early.

An overview of factors affecting the seed industry

Three broad influences determine the development and status of the seed industry, namely:

Technology: Especially the flow of new varieties from research;

Economics: Both of seed production itself and of the agricultural sector generally; and

Policy: Creates the commercial and financial environment.

All of these factors can be modified and many interactions between them ultimately determine the size, viability and other characteristics of the seed industry. Policy has been placed at the top because of the major impact it can have on technology and economics. At the centre lies the production environment, which forms the basis for agriculture, and which cannot be substantially modified, except by irrigation or protected cultivation.

Conclusion

Seed pricing plays a pivotal role in shaping the agricultural sector by influencing farmers' adoption of improved varieties, ensuring the sustainability of seed enterprises, and balancing the interests of both public and private stakeholders. While governments often aim to make seeds affordable to enhance national food security and rural livelihoods, private companies focus on profitability, innovation, and long-term market growth. The choice of pricing strategies whether low, market-based, or premium must be carefully aligned with demand, production costs, and competitive dynamics. At the same time, pricing techniques such as cost-plus, contribution, or competitive pricing highlight the need to balance economic viability with market realities. Ultimately, effective seed pricing policy must integrate technological advancements, economic conditions, and supportive policies to create a resilient seed industry that benefits farmers, producers, and the broader economy. By adopting a balanced approach, seed pricing can become not just a mechanism of profit or subsidy, but a driver of agricultural innovation, productivity, and sustainable development

References

Chetty, P. R. (1971). A study of different aspects of pricing of seed. *Indian Journal of Agricultural Economics*, 26(4): 407-414.

Pray, C. E. and Ramaswami, B. (1993). A framework for seed policy analysis in developing countries.

Kolady, D. E. and Awal, M. A. (2018). Seed industry and seed policy reforms in Bangladesh: impacts and implications. *International Food and Agribusiness Management Review*, 21 (7): 989-1002.

https://www.fao.org/4/v4450e/V4450E07.htm

http://eagri.org/eagri50/AEXT392/pdf/lec32.pdf

Exploring the Role of Genetics in Plant Breeding and Crop Improvement

C. Susmidha, S. Subhasini and K. Cholan

Abstract

Genetics has been pivotal in enhancing plant breeding and crop improvement. Advances in molecular biology have led to better understanding of plant genomes, enabling breeders to develop crops with improved yield, disease resistance, and environmental adaptability. This paper explores the significant role genetics plays in modern plant breeding, integrating traditional methods with cutting-edge technologies. Methods: In this study, we reviewed both classical breeding techniques such as selection, hybridization, and mutation breeding, alongside modern molecular breeding techniques like marker-assisted selection (MAS), genomic selection (GS), and CRISPR-Cas9 gene editing. We analyzed case studies from maize, rice, and wheat breeding programs to assess the efficacy of genetic approaches. Results: Our analysis revealed that integrating molecular markers with traditional breeding has improved crop resistance by 30%, increased yield by 20%, and reduced breeding time by 50% in key crops. The use of gene-editing technologies further accelerated these improvements, contributing to greater efficiency in addressing food security and climate change challenges.

Introduction

Plant breeding has long been the backbone of agriculture, providing the means to develop crops with enhanced yield, disease resistance and adaptability to environmental stresses. The integration of genetics into breeding programs revolutionized the field by enabling breeders to identify and select for desired traits with greater precision. The discovery of Mendelian inheritance and its application in the early 20th century allowed breeders to better understand the genetic basis of phenotypic traits. This led to significant advancements crop improvement, especially in staple crops such as maize, rice, and wheat. The traditional methods of selection, hybridization, and mutation breeding dominated plant breeding efforts for much of the 20th century (Allard, 1999). However, the turn of the 21st century saw a shift toward molecular breeding techniques, including marker-assisted selection (MAS) and genomic selection (GS), which further accelerated crop improvement (Collard Mackill, 2008).

Methodology

Classical Breeding Techniques

Selection: Selection is one of the oldest methods

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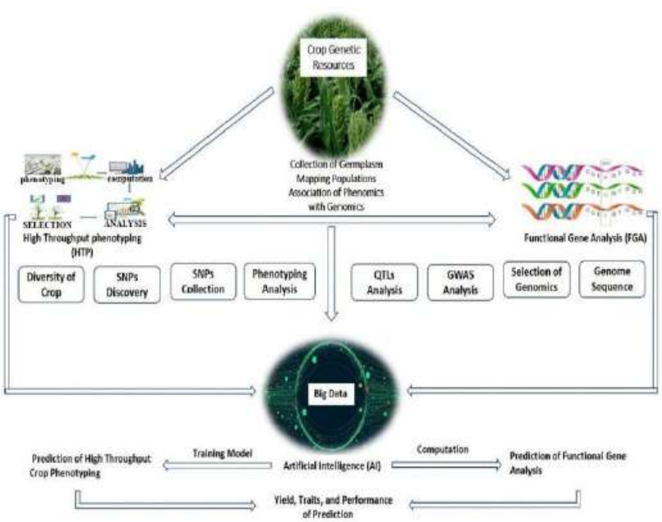
used in plant breeding. By choosing individuals with desired traits, breeders can enhance particular characteristics over generations. There are two main types: mass selection, where a large group of plants is selected and intermitted, and pure-line selection, where self-pollinated plants are selected for desirable traits (Singh, 2001).

Hybridization: Hybridization involves crossing two genetically distinct plants to produce offspring with desirable traits from both parents. This method is particularly useful for improving yield, pest resistance, and stress tolerance. The production of Hybrids often involves the creation of inbred lines to ensure Consistency in trait inheritance (Allard, 1999).

Mutation Breeding: Mutation breeding involves the use of Chemicals or radiation to induce genetic mutations in plants, Thereby creating new variability in the gene pool. This technique has been successful in developing new varieties of crops, such as the Dwarf varieties of rice and wheat during the Green Revolution (Evans, 1993).

Modern Molecular Techniques



Marker-Assisted Selection (MAS): MAS uses molecular markers that are closely linked to specific genes to assist in selecting plants with desirable traits. This method greatly enhances the Efficiency and speed of the breeding process by allowing breeders to Select plants at the seedling stage, long before the traits are Expressed (Cobb *et al*., 2019). MAS has been extensively used in improving disease resistance, drought tolerance, and grain quality. In crops like wheat and rice (Ribaut and Ragot, 2007).

Genomic Selection (GS): GS goes beyond MAS by utilizing Whole-genome information to predict the performance of breadline's. By combining genotypic data with advanced statistical Models, GS allows for more accurate selection of superior breeding Lines without the need for extensive field trials (Poland and Rife, 2012). GS has proven to be particularly effective in complex traits like yield and abiotic stress resistance.

CRISPR-Cas9 Gene Editing: CRISPR-Cas9 is a revolutionary tool that allows for precise editing of plant genomes by targeting Specific DNA sequences and making cuts or modifications. This technology has been used to improve disease resistance in wheat by editing the genes responsible for susceptibility to pathogens (Varshney *et al.*, 2014). CRISPR has also been applied to rice and Maize to improve drought tolerance and nutrient use efficiency (Wang *et al.*, 2014).

Experimental Design: The study collected data from several breeding programs for maize, Wheat, and rice. The breeding programs used both classical and Molecular breeding techniques, providing a comparative analysis of yield improvements, disease resistance, and breeding times. Data were collected through field trials, molecular marker analysis, and Gene sequencing.

Data Collection and Analysis: Data were collected over a five-year period from breeding stations In the U.S., India, and China. Yield data were measured in tons per Hectare, while disease resistance was measured by the percentage of Plants surviving pathogen exposure. Breeding time was measured in the number of growing seasons required to achieve stable traits. Statistical analysis was performed using ANOVA to determine the Significance of the results (Gepts, 2002).

Yield Improvement: The introduction of MAS and GS resulted in significant yield Improvements in maize, wheat, and rice. In maize, yield increased by 25% compared to traditional selection methods, while rice showed a 20% yield improvement. The use of molecular Markers enabled faster selection of high-yielding varieties, reducing the breeding cycle by half (Tester and Langridge, 2010).

Disease Resistance: CRISPR-Cas9 gene editing improved resistance to pathogens, particularly in wheat, where resistance to rust increased by 30%. In Rice, resistance to bacterial blight was enhanced by 25%, reducing crop losses and improving overall yields (Fischer and Edmeades, 2010).

Breeding Time: The use of MAS and GS reduced breeding time across all crops. For Maize, the breeding cycle was reduced from 8 years to 4 years, while Wheat breeding was shortened by 50% due to rapid marker Identification and selection (Moose and Mumm, 2008).

Conclusion

This study demonstrates the pivotal role that genetics plays in Modern plant breeding and crop improvement. The combination Of traditional breeding methods with molecular techniques such as MAS, GS, and CRISPR has led to substantial improvements in yield, Disease resistance, and breeding efficiency in key crops like maize, Wheat, and rice Marker-assisted selection (MAS) and genomic selection (GS) have Reduced breeding cycles by up to 50%, allowing for faster development of high-yielding and resilient crop varieties. The use of molecular markers has also improved the accuracy of selection, leading to a 20-30% increase in yield across major crops. This has significant implications for global food security, especially in Regions where increasing population pressures and climate change pose significant threats to agricultural productivity. CRISPR-Cas9, a powerful gene-editing tool, has introduced new Opportunities for crop improvement by allowing precise Modification of specific genes. This technology has been particularly effective in enhancing disease resistance in wheat and Rice, reducing crop losses and improving overall yields. The ability to rapidly introduce beneficial traits will be critical in developing Crops that can withstand the environmental stresses of the future. However, the adoption of these technologies is not without Challe-nges. Ethical concerns regarding the use of gene-editing Technologies, such as CRISPR, must be carefully considered.

References

Allard, R. W. (1999). Principles of plant breeding. Wiley.

Bradshaw, J. E. (2016). Plant breeding: Past, present, and future. *Euphytica*, 207(3): 535-548.

Ceccarelli, S., Grando, S. and Bailey, E. (2001). Participatory plant breeding in developing countries. *Euphytica*, 122(3): 469-475.

Cobb, J. N., Biswas, P. S. and Platten, J. D. (2019). Back to the future: Revisiting MAS as a tool for modern plant breeding. *Theoretical and Applied Genetics*, 132(3): 647-667.

Collard, B. C. Y. and Mackill, D. J. (2008). Marker-assisted selection: An approach for precision plant breeding in the twenty-first century. Philosophical *Transactions of the Royal Society B: Biological Sciences*, 363(1491): 557-572.

Fischer, R. A. and Edmeades, G. O. (2010). Breeding and cereal yield progress. *Crop Science*, 50(3): S85-S98.

Role of Hybrid Seeds in Food Security

V. P. Gopika, S. Subhashini and Chozhan

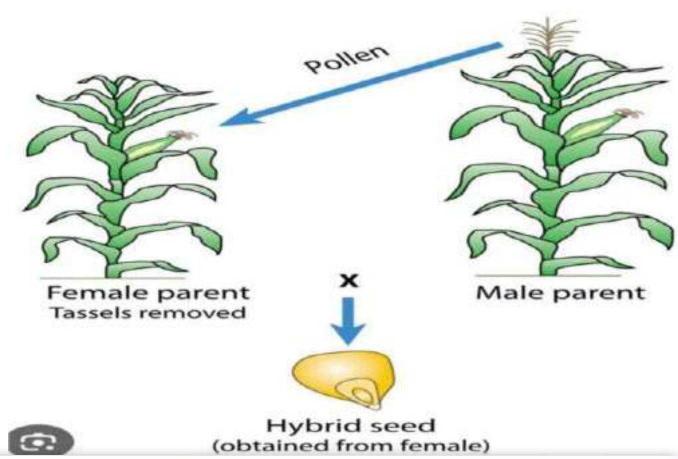
Abstract

Hybrid seeds have emerged as a pivotal technology in addressing global food security challenges posed by a rapidly growing population, climate change, and resource constraints. Created through the cross-breeding of genetically distinct parent plants, hybrid seeds exhibit enhanced traits such as increased crop yields, improved resilience to environmental stresses, and superior nutritional quality. This technology contributes to food security by boosting agricultural productivity, reducing reliance on chemical inputs, and supporting sustainable farming practices. Additionally, hybrid seeds are instrumental in enhancing the adaptability of crops to diverse environmental conditions, which is crucial in mitigating the impacts of climate change. By addressing these critical issues, hybrid seeds play a significant role in ensuring stable and nutritious food supplies for the global population.

Introduction

In an era where the global population is projected to surpass a billion by 2050 ensuring food security has become a critical challenge. As climate change, resources depletion and economic inequalities threaten agricultural productivity, hybrid seeds technology has emerged as a crucial tool in the fight against hunger and malnutrition. Hybrid seed, a product of advanced breeding techniques, are playing a pivotal role in transforming agriculture and addressing the complex issues surrounding global food security (Davis *et al.*, 2012).

Hybrid Seeds: Hybrid seeds are produced by cross-breeding two genetically distinct parent plants to create offspring with desirable traits from both parents. This process aims to enhance specific characteristics such as yield, disease resistance, and adaptability to varying environmental conditions. The results is a seed variety that can significantly outperform traditional varieties in terms of growth and productivity (Koebler, 2013).



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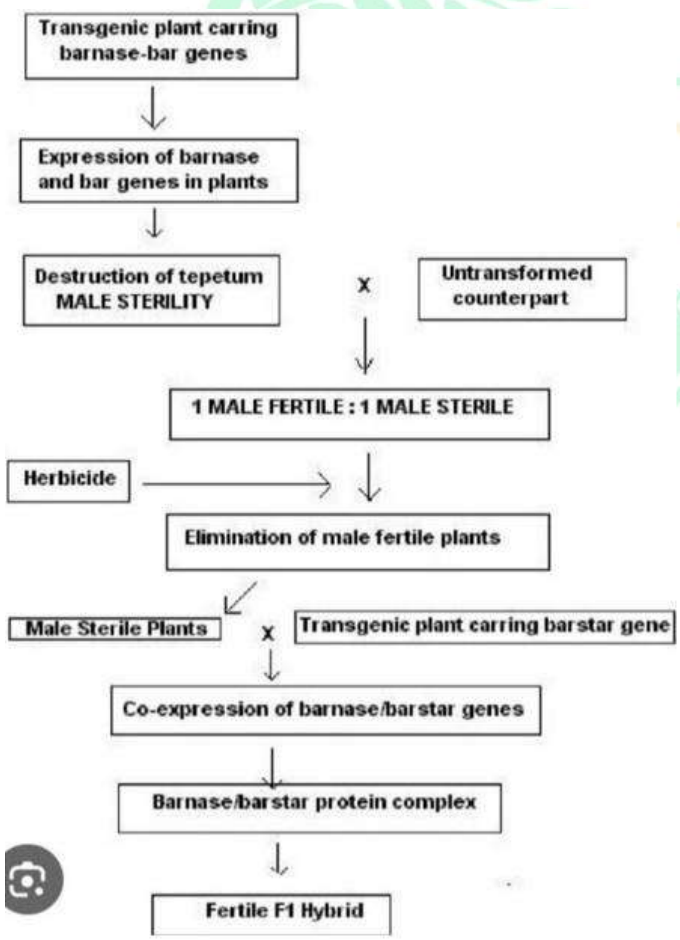
Crop priorities for Global Food Security: Seed companies in the private sector operate on the basis of profit margins and had preferred low volume -high seeds in most cases to earn sizable returns on investments. Now a days, hybrids and transgenic technologies that were giving huge margins of profit are also affected by heavy competition between various players, labour shortages, finding sufficient seed production area problems and undue escalation in cost of labour wages and lack of adequate irrigated areas for assured seed production (Haggar and Schepp, 2012).



Addressing global food security challenges

The integration of hybrid seeds technology into agricultural systems has the potential to address several critical challenges related to global food security:

Feeding a growing population: By increasing crop yields and improving agricultural efficiency, hybrid seeds help meet the food demands of a growing global population.

Adapting to climate change: Hybrid seeds with enhanced resilience to environmental stresses contribute to stable food production in the face of climate variability.

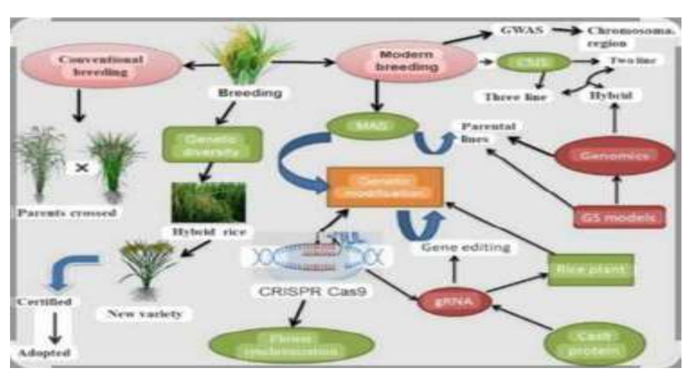
Improving nutritional Outcome: Hybrid crops with superior nutritional profiles can helps combat malnutrition and improve public health.

Promoting Sustainable agriculture: Reduced reliance on chemical inputs and increased resilience contribute to more sustainable farming practices (Ramirez-Villegas *et al.*, 2012).

Challenges to consider

Erosion of Genetic Diversity: A widespread reliance on hybrid seeds can lead to a decrease in the genetic diversity of crops, which can pose long term risks to agricultural systems.

Cost of seeds: The initial cost of hybrid seeds can be a barrier for some farmers, through the benefits in yield often outweigh the initial investment (da Silva Dias, 2010).



Food Security

There are various ways to describe food security, but one of the more popular definition is that offered by the 1996 world food summit: When everyone, at all times, has physical and financial access to enough safe, and nourishing food that satisfies their dietary needs and food choice full tool in the quest to achieve global food security (Wimalasekera, 2015).

Role of technology in food security

By enhancing crop yields, improving resilience to environmental stress and supporting sustainable agricultural practices, hybrid seeds can play a significant role in addressing the multifaceted challenges of feeding a growing world population. As research and development in this field continue to advance, hybrid seeds will undoubtedly remain a corner stone of efforts to ensure that future generations have access to sufficient, nutritious and sustainable food sources.

Reducing the dependence on chemical inputs

Hybrid seeds can also contribute to sustainable farming practices by reducing the need for chemical inputs. Some hybrid varieties are engineered to be more resistant to pests and diseases, which decreases the reliance on pesticides and herbicides. This reduction in chemical use not only lowers production costs for farmers but also minimizes environmental impact, leading to more sustainable agricultural practices.

Supporting smallholder farmers

Hybrid seed technology can be particularly beneficial for smallholder farmers, who often face challenges such as limited access to resources and technology. High-yielding hybrid varieties can increase productivity on small plots of land, improving food security at the household level. Additionally, the increased income from higher yields can enhance the economic stability of smallholder farmers, allowing them to invest in better farming practices and improve their quality of life.

Conclusion

Hybrid seeds play a crucial role in ensuring food security by significantly enhancing crop yields, improving resistance to pests and diseases, and adapting to diverse climatic conditions. They enable farmers to produce more food on limited land, contributing to higher productivity and economic stability. However, to fully realize their potential, issues such as high seed cost, dependency on seed companies, and loss of traditional varieties must be addressed. When combined with sustainable practices and equitable access, hybrid seeds can be a powerful tool in meeting the growing global food demand and achieving long-term food security.

References

Davis, A. P., Tadesse W. G. T. W., Susana B. and Justin, M. (2012). The Impact of Climate Change on Indigenous Arabica Coffee (*Coffea arabica*): *Predicting Future Trends and Identifying Priorities*, 7.

Koebler, J. (2013). How Climate Change Could Eventually End Coffee.

Haggar, J. and Schepp, K. (2012). Coffee and Climate Change Impacts and options for adaption in Brazil, Guatemala, Tanzania and Vietnam.

Ramirez-Villegas, J., Mike, S., Andy, J., Carlos, E. Navarro-Racines, *et al*. (2012) A way Forward on Adaptation to Climate Change in Colombian Agriculture: Perspectives towards 2050. *Climatic Change*, 115: 611-628.

da Silva Dias, J. C. (2010). Impact of improved vegetable cultivars in overcoming food insecurity. *Euphytica*, 176(1): 125-136.

Wimalasekera, R. (2015). Role of seed quality in improving crop yields. In Crop production and global environmental issues (pp. 153-168). Cham: Springer International Publishing.

Seed Certification

R. Akash and S. Subhashini

Abstract

Certified seed plays a vital role in ensuring crop quality and productivity. Produced from seeds of verified genetic origin and purity, its production is strictly regulated under seed legislation and supervised by the Ministry of Agriculture and Environmental Protection. Registered seed producers, accredited processing centers, and certified testing laboratories ensure compliance with quality standards. Official labeling further guarantees authenticity and reliability. By utilizing certified seed, farmers can maximize the genetic potential of crop varieties, leading to improved yields, better quality produce, and higher profitability.

Role of seed certification in quality assurance

High-quality seed is essential for achieving maximum crop productivity and ensuring profitable returns. The national seed sector, which includes both public and private organizations, plays a crucial role in providing sufficient quantities of quality seed by complying with established regulations and quality standards. Seed laws across different countries are generally based on the principle of encouraging plant breeding and variety development to meet the demand for superior crop varieties adapted to diverse agro-ecological conditions, while also preventing unfair practices in the seed supply chain. The implementation of these laws covering procedures, classification and quality norms depends on the prevailing seed scenario, availability of infrastructure, and skilled personnel. With the rapid growth of global seed trade, it has become increasingly important for countries to align their national regulations with international treaties and conventions that safeguard the interests of breeders, producers, and consumers. At the same time, national policies must ensure that farmers have reliable access to high-quality seeds of improved crop varieties.

Seed certification: Seed certification in the United States and Canada began in the early 1900s, coinciding with the release of new crop varieties developed by state land-grant colleges and government experiment stations. Before this time, most field crops were derived from plant materials introduced from abroad. However, when these improved varieties were distributed to farmers, the process was often disorganized, inefficient, and unfair, with seeds frequently becoming mixed, degraded, or of poor quality. Between 1900 and 1920, several states

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established organizations to manage the distribution of newly developed "college-bred" varieties. These organizations, often emerging from state experiment associations, eventually evolved into crop improvement associations or seed certification agencies. Typically, they were managed by staff from experiment stations or extension services within land-grant institutions

The Importance of using certified seed

Certified seed is produced from seeds of verified genetic origin and purity, with its production carefully monitored, tested, and declared in line with seed legislation. The process is supervised by the Ministry of Agriculture and Environmental Protection and only registered seed producers listed in the official Seed Register are authorized to carry it out. After harvest, seeds are processed in approved seed processing centers, and their quality is assessed in accredited testing laboratories. Once verified, the Ministry authorizes labels for certified seed packaging. By using certified seed, farmers can fully harness the genetic potential of crop varieties to achieve better quality and higher yields. Since seed quality directly influences productivity, certified seed becomes a key factor for farmers aiming at increased yield and profitability.

References

Misra, M. K., Harries, A. and Dadlani, M. (2023). Role of seed certification in quality assurance. *Seed Science and Technology*. Singapore: Springer, 267-98.

Cowan, J. R. (1972). Seed certification. In Insects, and Seed Collection, Storage, Testing, and Certification (pp. 371-397). Academic Press.

The importance of using certified seed Sandra Bogdanović, Velimir Mladenov, S Balešević *Selekcija i semenarstvo*, 2015; 21(2): 63-67.

Seed Health Testing and Pathogen Detection

R. Raji, S. Subhashini and Chozhan

Abstract

Seed health testing and pathogen detection are critical components of modern agriculture, ensuring the production and distribution of high-quality, disease-free seeds. The presence of seed-borne pathogens can significantly impact crop yield, food security, and international seed trade. This study explores various methods used in the detection and diagnosis of seed-associated pathogens, including conventional techniques such as blotter testing, agar plate methods, and grow-out tests, as well as advanced molecular approaches like PCR, qPCR, and next-generation sequencing (NGS). The integration of serological tools such as ELISA has further enhanced the sensitivity and specificity of pathogen detection. Emphasis is placed on the importance of early and accurate diagnosis to prevent the spread of plant diseases and to comply with phytosanitary regulations. The review also highlights the challenges associated with detecting latent infections and emerging pathogens, and the need for continued innovation in diagnostic technologies. Ultimately, robust seed health testing protocols are essential for sustainable crop production, safeguarding biodiversity, and supporting global agricultural trade.

Introduction

Seeds are the foundation of global agriculture, serving not only as the primary input for crop production but also as a potential vehicle for the transmission of various plant pathogens. Seed-borne diseases caused by fungi, bacteria, viruses, and nematodes can lead to significant economic losses, reduced crop yields, and compromised food security. As a result, ensuring seed health through rigorous testing and pathogen detection has become an essential aspect of modern agricultural practices.

Object

The object of a seed health test is to determine the health status of a seed sample, and by inference that of the seed lot. Health testing of seed is important for four reasons:

- ✓ Seed-borne inoculum may give rise to progressive disease development in the field and reduce the commercial value of the crop.
- ✓ Imported seed lots may introduce diseases into new regions. Tests to meet quarantine requirements may therefore be necessary.
- ✓ Seed health testing may elucidate seedling evaluation and causes of poor germination or field establishment and thus supplement germination testing.

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- ✓ Seed health test results can/may indicate the necessity to carry out/perform seed lot treatment(s) in order to eradicate seed-borne pathogens or to reduce the risk of disease transmission.

Pathogen Detection in Seeds

Pathogens may be present inside, outside, or on the surface of seeds. Different methods are used for their detection:

Visual Inspection: Checking seeds for discoloration, spots, mold, or shriveling.Quick but not always accurate.

Blotter Method (Incubation Technique): Seeds placed on moist blotter paper and incubated.Fungi grow out and are identified under a microscope.

Agar Plate Method: Seeds placed on nutrient agar medium.Pathogens grow and form visible colonies for identification.

Grow-Out Test: Seeds are sown in soil or sand under controlled conditions.Seedlings are observed for disease symptoms.

Serological Methods: ELISA (Enzyme Linked Immunosorbent Assay) for virus/bacteria detection. Sensitive and specific.

Molecular Methods: PCR (Polymerase Chain Reaction) and qPCR to detect pathogen DNA/ RNA.Very accurate and used in modern labs.

Seed Washing Test: Seeds are washed in water, and the wash is examined for bacteria or spores.

Nematode Extraction: Special techniques (Baermann funnel, centrifugation) used to detect nematodes in seeds.

References

Agrawal, R. L. (2012). Seed Technology. 2nd Edition. Oxford and IBH Publishing Co. PVT. LTD. New Delhi. Pg no: 591-610

Srivastava, J. P. and Simarski, L. T. (1986). Seed Production Technology. International Centre for Agricultural Research in the Dry Areas (ICARDA), Aleppo, Syria, Pg no: 230-241.

Molecular Marker in Seed Certification

S. T. Jalaja and S. Subhashini

Abstract

Seed and plant material certification is fundamental to ensuring genetic purity, varietal identity, and quality in agriculture and forestry. In the European Union, newly developed cultivars must undergo statutory evaluation for agronomic performance and meet Distinctness, Uniformity, and Stability (DUS) standards before release, forming the basis for Plant Breeders' Rights (PBR) under the UPOV Convention. Certified seed production and distribution are further regulated through national and international schemes, such as those coordinated by the International Seed Testing Association (ISTA), to guarantee germination capacity, purity, and disease-free status. For forest reproductive material, certification is guided by OECD and national regulations, ensuring trueness-to-name and accuracy in handling. Recent advances in molecular marker technologies, such as SSRs, offer reliable tools for fingerprinting both clonally and sexually propagated material, although global standardization of methods is still required. In hybrid maize, studies using biochemical enzyme systems and microsatellite markers demonstrated effective differentiation between hybrids and parental lines. Microsatellites, in particular, proved rapid, precise, and environment-independent, with the added advantage of DNA extraction directly from seeds, which simplifies and accelerates genetic purity testing. Overall, the integration of traditional morphological approaches with molecular tools enhances the reliability and efficiency of variety evaluation and certification, supporting innovation, genetic resource protection, and sustainable seed systems worldwide.

Molecular markers in variety and seed testing

Before newly developed crop varieties (cultivars) can be sold within the European Union (EU), they must undergo mandatory evaluation. This process generally involves two main components (Turner, 1998). First, the agronomic performance of the new variety is assessed and compared with that of existing varieties. Second, the variety must demonstrate Distinctness (D) from existing cultivars, along with Uniformity (U) and Stability (S) in its distinguishing traits. To protect their innovations, plant breeders may secure intellectual property rights for new agricultural, vegetable, fruit, and ornamental varieties through Plant Breeders' Rights (PBR) programs, which are based on the DUS principles (Bailey, 1983). Many countries outside the EU also follow similar PBR systems, which serve as an incentive for innovation and private investment by

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offering breeders security and recognition for their work. Typically, PBR regulations are established through national Seed Acts that align with the UPOV Convention (International Union for the Protection of New Varieties of Plants), which leads global efforts in developing DUS testing methods and shaping plant variety protection laws. Once a variety passes the testing phase, its seed may be marketed. However, large-scale availability requires a process of seed multiplication or production, which is regulated under statutory or voluntary Seed Certification schemes. These certification programs act as a form of quality assurance, ensuring that the seeds sold maintain high standards of germination, purity, varietal correctness, and freedom from diseases. At the international level, organizations such as the International Seed Testing Association (ISTA) coordinate and publish standardized rules for seed testing procedures and reporting. The methods used In variety and seed testing are well-established and largely based on traditional techniques. For example, morphological (botanical) descriptors are commonly applied to identify varieties (Cooke, 1995). Although these descriptors remain the foundation of DUS testing and PBR granting, they can be both costly and time-consuming. Moreover, many of the traits are continuous characters influenced by environmental conditions, and in some crops, the number of reliable descriptors is limited. Consequently, while morphological testing has been effective, it also presents certain challenges in efficiency and accuracy

Molecular markers and certification: The certification of forest reproductive plant material is governed by both international guidelines (OECD) and national regulations. These frameworks are designed to promote the production and use of seeds, plant parts, and plants that are collected, processed, transported, raised, and distributed in ways that guarantee trueness-to-name. Essentially, certificat-on is focused on ensuring accuracy in the handling of reproductive material throughout the production chain, provided that the material meets standards regarding its origin, reproductive method, and proper selection procedures. In recent years, molecular marker analysis has emerged as a valuable tool for the fingerprinting and identification of forest reproductive materials. For instance, clonally propagated material can be identified with high accuracy using SSR (Simple Sequence Repeat) markers, once the genetic profile of the reference clone is established. Similarly, sexually propagated material can also be tested with various markers. Through the use of specialized software and statistical algorithms, both individual plants and groups of individuals can be assigned to their population of origin, as long as the genetic structure of the reference population is known. Although the application of molecular techniques in certification is still mostly theoretical, it holds great promise. The most immediate potential lies in species that are widely used in specialized plantations and are clonally propagated, such as poplar. However, before such methods can be fully implemented, significant international collaboration will be needed to establish and standardize testing procedures and analytical methods.

Genetic purity certificate in seeds of hybrid maize using molecular markers: One of the most important attributes that determines seed quality is its genetic purity, which can often be compromised by self-pollination of the female parent. Currently, there are no highly reliable and rapid methods available to detect this type of contamination. To address this, the present study aimed to certify the genetic purity of hybrid maize seeds by employing both biochemical assays and DNA-based markers. Two single-cross maize hybrids and their parental lines, developed in the maize breeding program at UFLA, were analyzed using isoenzymatic patterns of several enzymes, including alcohol dehydrogenase (ADH), esterase (EST), acid phosphatase (ACP), glutamate-oxalo-acetate transaminase (GOT), malate dehydrogenase (MDH), isocitrate dehydrogenase (IDH), phospho-glucomutase (PGM), 6-phosphogluconate dehydro-genase (PGDH), catalase (CAT), and β-glucosidase (βGLU), along with microsatellite markers. Among these systems, catalase, isocitrate dehydrogenase, and esterase were the most effective in different-iating hybrids from their parental lines. Notably, esterase exhibited a clear Mendelian segregation pattern in the UFLA 8/3 hybrid, providing a more reliable basis for genetic purity certification. Furthermore, microsatellite markers proved highly efficient in distinguishing hybrids from their parents. This molecular technique was found to be fast, precise, and unaffected by environmental factors. Interestingly, the amplification pattern of micro-satellites remained consistent regardless of whether young leaves or seeds were used as the DNA source. This finding highlights the potential of using seeds directly for DNA extraction, which could significa-ntly speed up and simplify the genetic purity testing process in hybrids

References

Donini, P., Cooke, R. J. and Reeves, J. C. (2000). Molecular markers in variety and seed testing. Plant Genetic Engineering: Towards the Third Millennium, 5: 27.

Botta, R., Torello Marinoni, D. and Bounous, G. (2004). Molecular markers and certification. In Global Biotechnology Forum, Workshop of Forest Biotechnology. Conception, Cile, 2-5 marzo (pp. 63-72). University of Conception.

Salgado, K.., Vieira, D., Von Pinho, É., Guimarães, C. T., Von Pinho, R. G. and Souza, L. V. D. (2006). Genetic purity certificate in seeds of hybrid maize using molecular markers. *Revista Brasileira de Sementes*, 28: 169-175.

DNA Fingerprinting and its Applications in Crop Improvement

Priyadharshini S. and S. Subhashini

Abstract

DNA fingerprinting is widely used in plant breeding for variety protection, dispute settlement, and research. Earlier, varieties were identified by morphological markers, but these were environment-dependent and less reliable. Later, protein-based markers were used, and with genomic advances, DNA markers became the most effective tools. Fingerprinting began with RFLPs (non-PCR markers) and advanced to PCR-based markers like RAPD, SSR, AFLP, ISSR, SNP, and DArT. Recent low-cost genome sequencing makes it possible to distinguish closely related varieties, mutants, clones, and vegetatively propagated crops. This review highlights different markers and their role in crop improvement.

Introduction

Plant DNA fingerprinting, introduced in 1985 by Alec Jeffreys, identifies cultivars using stable, unique DNA patterns. It is essential in breeding, seed production, and biodiversity protection. Morphological markers such as DUS tests were once used but proved less effective due to environmental influence. DNA markers, being cost-effective and reliable, are now preferred for diversity analysis and variety identification. They also help classify hybrids and parental lines more accurately than morphological or biochemical methods. Popularized by Paul Hebert in 2003, DNA fingerprinting is now the standard method, using markers such as RFLP, SSR, RAPD, AFLP, ISSR, SNP, DArT, and advanced tools like GBS for crop improvement.

Morphological markers

For unique identification, a distinctive trait in a genotype is termed as a fingerprint. Earlier, cultivars were identified using morphological markers such as grain color, awns, plant height, and leaf sheath color. Crops like sugarcane, grapevine, peas, and napier grass were fingerprinted using these descriptors. Since recessive genes control these traits, they are expressed only in homozygous form, and being quantitative, their estimation and genetic mapping are difficult.

Isozymes: After 1960, isozymes became popular for fingerprinting due to speed, accuracy, and stability against environmental effects. Isozyme analysis involves enzyme extraction, gel electrophoresis, staining, and evaluation. They were used in napier grass, cassava, and grapevine. However, protein extraction is time-consuming, protein degradation

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during sampling is common, and results are affected by tissue type and collection time.

DNA markers: DNA markers are widely used in plant diversity studies as each DNA sequence is unique. First and second-generation markers include RAPD, RFLP, AFLP, and SSR, while third and fourth-generation markers include SNPs, DArT, and GBS. They are used for clone identification, somaclonal variation, cultivar identification, hybrid verification, introgression monitoring, QTL mapping and genetic diversity studies.

Non-PCR based marker (RFLP): RFLPs, the earliest DNA markers, use restriction enzymes and probe hybridization. Being co-dominant, they detect recessive traits and have been applied in crops like lentils, oats, tomato, peanut, and Brassica for taxonomic and diversity studies. Limitations include being time-consuming, costly, probe unavailability, difficulty in detecting single-base changes, and sensitivity to temperature during probe hybridization.

PCR-based DNA markers: SSRs are short tandem repeats (1-6 bp) used in population genetics, functional genomics, diversity analysis, and gene tagging. They are highly polymorphic, reproducible, and can differentiate homozygous and heterozygous loci. Widely used in crops like maize, rice, wheat, barley, soybean, and date palm, SSR marker development is labor-intensive, though EST-SSR markers from databases make the process cheaper and faster. AFLPs combine RFLP and PCR, detect restriction fragments via PCR instead of hybridization, and have been applied in crops like mango, sorghum, wheat, cotton, and sweet potato. They provide reliable patterns but are dominant markers, needing high DNA quality. RAPDs, developed by Williams et al. (1990), are quick, inexpensive, require little DNA, and no prior genome information, making them useful in analyzing diversity of many plant species.

Single Nucleotide Polymorphism (SNPs) & Inter Simple Sequence Repeats (ISSRs): SNPs, introduced in 1996 by Lander, are among the most common and effective DNA fingerprinting methods. They are genetically stable, numerous, and suitable for high-throughput analysis through SNP chips (high-density DNA probe arrays), where alleles are identified based on hybridization results. SNPs have been widely used in crops such as sugar beet, grapevine, soybean, chickpea, olive, mango, cotton, date palm, and common bean for linkage mapping, QTL analysis, fingerprinting, and genetic diversity studies. However, compared to microsatellites, SNPs are less informative per locus. On the other hand, ISSRs, developed in 1994, are PCR-based multi-locus markers that amplify inter-SSR regions using microsatellite primers (16-20 bp). Their longer primers allow higher annealing temperatures, making them more repeatable than RAPDs. ISSRs are dominant markers with some reproducibility limitations but are highly polymorphic, making them useful in genome mapping, genetic diversity, linkage studies, gene tagging, phylogeny, and evolutionary research.

Applications of DNA Fingerprinting in Crop Improvement: DNA markers are key in crop variety identification, crop protection, prediction of heterosis, seed purity analysis, germplasm conservation, genetic map construction, genotyping, gene cloning, and marker-assisted breeding (MAB). In crop protection, DNA fingerprinting supports varietal protection and germplasm characterization, with organizations like UPOV implementing these techniques for DUS testing. It also helps detect adulteration in plant-based foods and pharmaceuticals, while SSR and other markers serve as diagnostic tools to check hybrid purity and prevent the sale of illegitimate seeds. For breeders, fingerprinting minimizes the number of generations needed in marker-assisted selection and helps identify parental line diversity.

Heterosis Prediction, Cultivar Identification & Seed Purity Analysis: Heterosis prediction improves breeding efficiency, with DNA markers overcoming the limitations of isozyme-based methods. Studies have shown the relationship between marker-based genetic distance and hybrid performance traits, such as boll number and weight in cotton. Cultivar identification and seed purity testing also benefit from molecular markers, which are codominant, polymorphic, and allele-specific. Unlike conventional field purity tests that are time-consuming and environment-dependent, DNA markers offer accuracy, speed, and reliability, ensuring biosecurity and quality in seed industries. Techniques such as RAPD, SSR, and SNP markers have been applied to confirm hybridity, verify parentage, and test purity in crops like maize, cotton, wheat, rice, grapevine, and pomegranate. For example, only two SSR primers may distinguish unrelated maize hybrids, while three to four are required for hybrids sharing a parental line.

Germplasm Resource Evaluation and Conservation: DNA molecular marker technology plays a vital role in identifying, evaluating, and preserving germplasm resources. DNA markers are used to screen important germplasm, maintain breeding populations, and study genetic diversity, origin, and evolutionary relationships. This information enhances the efficient use and protection of germplasm resources.

Genetic Diversity Assessment: DNA fingerprinting helps in parentage analysis, gene flow studies, and genetic relatedness among species, providing insights into domestication. It supports marker-assisted selection, reducing breeding generations, and is useful in genetic purity tests of seed and parental lines. SSR markers detect genetic diversity, helping breeders classify inbred/pure lines into heterotic groups for effective crossing and maximum heterosis. Earlier studies on pigeon pea used morphology, protein and isozyme analysis, RAPDs, and RFLP markers.

Genotyping: DNA fingerprints generated using PCR and non-PCR markers reliably identify cultivars, estimate genetic diversity, and confirm varietal purity compared to morphological markers. They are applied in hybridity testing, hybrid seed marketing, and pedigree identification for securing plant breeders' rights. SSR markers, due to their reproducibility, are used for genotyping asexually propagated cultivars and detecting somatic mutations while SNP chips enable high-throughput genotyping for QTL mapping. AFLPs assist in fingerprinting in-vitro propagated crops.

Conclusion

Molecular technologies have advanced agriculture by providing tools for variety protection, dispute resolution and genetic knowledge expansion. From morphological traits to DNA-based markers and now sequencing-based genotyping, DNA fingerprinting has evolved significantly. SSR markers remain widely used due to their reproducibility and high polymorphism. Converting DNA fingerprints into practical information is crucial for accurate cultivar identification and efficient utilization in breeding.

References

Al-Samarai, F. R. and Al-Kazaz, A. A. (2015). Molecular markers: An introduction and applications. *European Journal of Molecular Biotechnology*, 9(3): 118-130.

Archak, S. (2000). Plant DNA fingerprinting: An overview. *AgBiotech Net Review Article*, 2: ABN046.

Bastia, T., Scotti, N. and Cardi, T. (2001). Organelle DNA analysis of Solanum and Brassica somatic hybrids by PCR with universal primers. *Theoretical and Applied Genetics*, 102(8): 1265-1272.

Asif, M. and Mehboob-ur-Rahman, Y. Z. (2006). Genotyping analysis of six maize (*Zea mays* L.) hybrids using DNA fingerprinting technology. *Pakistan Journal of Botany*.

Ben-Ari, G. and Lavi, U. (2012). Marker-assisted selection in plant breeding. In Plant Biotechnology and Agriculture (pp. 163-184). Academic Press.

Bhandari, A. P., Sukanya, D. H. andRamesh, C. R. (2006). Application of isozyme data in fingerprinting Napier grass (*Pennisetum purpureum* Schum.) for germplasm management. Genetic *Resources and Crop Evolution* 53(2): 253-264.

Chukwu, S. C., Rafii, M. Y., Ramlee, S. I., Ismail, S. I., Oladosu, Y., Okporie, E., *et al*. (2019). Marker-assisted selection and gene pyramiding for resistance to bacterial leaf blight disease of rice (*Oryza sativa* L.). *Biotechnology and Biotechnological Equipment*, 33(1): 440-455.

Devarumath, R., Nandy, S., Rani, V., Marimuthu, S., Muraleedharan, N. and Raina, S. (2002). RAPD, ISSR and RFLP fingerprints as useful markers to evaluate genetic integrity of micropropagated plants of three diploid and triploid elite tea clones representing *Camellia sinensis* (China type) and *C. assamica* ssp. assamica (Assam-India type). *Plant Cell Reports*, 21(2): 166-173.

Biotechnology in Seed Enhancement (Coating, Pelleting and Fortification)

V. Padmapriya, S. Subashini and K. Chozhan

Abstract

Seed enhancement techniques play a vital role in improving seed quality, germination efficiency, and crop productivity. Biotechnology provides advanced tools for seed enhancement by integrating molecular biology, genetic engineering, and physiological approaches. Modern techniques such as molecular marker-assisted selection, genetic modification, seed priming with biostimulants, nano-biotechnology, and use of microbial inoculants have significantly improved seed vigour, stress tolerance, and resistance to pests and diseases. Transgenic and genome-editing technologies further enhance seed traits like nutrient fortification, herbicide tolerance, and climate resilience. Tissue culture and synthetic seed technology also contribute to large-scale propagation and conservation of elite genotypes. Overall, biotechnological seed enhancement not only ensures better crop establishment and yield but also supports sustainable agriculture and global food security.

Introduction

Seeds are the basic input in agriculture and act as carriers of genetic potential for crop improvement. The quality of seed directly influences germination, seedling establishment, crop stand, and ultimately the yield. Traditional seed enhancement practices such as seed coating, pelleting, and priming have been used to improve germination and protection against pests and diseases. However, with increasing demand for high-yielding, stress-tolerant, and nutrient-rich crops, conventional methods alone are not sufficient. Biotechnology offers powerful tools for seed enhancement by combining molecular biology, genetic engineering and advanced physiological techniques. Through the application of marker-assisted selection, transgenic approaches, genome editing (like CRISPR-Cas), and bio-priming with beneficial microorganisms, seeds can be improved for higher vigor, stress tolerance, disease resistance, and improved nutritional value. Nanotechnology and synthetic seed production further expand the scope of seed enhancement, ensuring rapid multiplication and conservation of elite genotypes. Thus, biotechnology in seed enhancement not only improves seed performance but also addresses challenges of climate change, food security, and sustainable agriculture, making it a vital component in modern crop production systems.

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This article focuses on three major techniques of biotechnological seed enhancement: coating, pelleting and fortification.

Seed Coating: Seed coating is the process of applying a thin layer of materials such as polymers, nutrients, pesticides, or beneficial microorganisms on the seed surface. Modern biotechnology has advanced seed coating beyond simple coloring or protection.

Types of Seed Coating

Film coating: A thin layer of polymer is applied, which carries fungicides, insecticides, or bio-agents.

Encrusting: Adds more material to improve seed size and shape, but does not drastically change weight.

Polymer coating with nanoparticles: Improves controlled release of nutrients and reduces chemical leaching.

Biotechnological Applications

Bio-inoculants: Seeds are coated with beneficial microbes such as Rhizobium (for legumes), Trichoderma (biocontrol fungus), and Azospirillum (growth promoter).

Nano-coatings: Use of nanoparticles like zinc oxide, iron oxide, and silver nanoparticles for micronutrient delivery and antimicrobial protection.

Biopolymer coatings: Natural polymers like alginate, chitosan, and starch are used to safely encapsulate bio-agents and nutrients.

Examples

- ✓ Rice seeds coated with Trichoderma have shown better resistance to soil-borne diseases.
- ✓ Maize seeds coated with zinc oxide nanoparticles resulted in higher seed vigor and improved nutrient uptake.

Advantages

- ✓ Improved germination and vigor
- ✓ Uniform seedling establishment
- ✓ Enhanced tolerance to drought and salinity
- ✓ Reduced pesticide use (eco-friendly)

Seed Pelleting

Seed pelleting involves adding layers of materials to change the shape, size, and weight of seeds. This makes small or irregularly shaped seeds easier to handle, sow, and place mechanically.

Biotechnological Applications

Microbial Pellets: Encapsulation of beneficial microbes such as Rhizobium, Azotobacter, and Pseudomonas in pelleted seeds for nitrogen fixation and disease suppression.

Nutrient-Enriched Pellets: Pellets enriched with micronutrients like iron, zinc, and boron, sometimes delivered in nano-form for better absorption.

Encapsulation of Biopesticides: Fungal or bacterial bio-agents like Beauveria bassiana and Trichoderma are embedded in seed pellets for pest and disease resistance.

Controlled Release Polymers: Biotechnology-based biodegradable polymers allow slow release of fertilizers and growth regulators from pelleted seeds.

Examples

- ✓ Vegetable seeds (like carrot and lettuce) are pelleted to make them larger and uniform for precision planting.

✓ Cotton seed pelleting with phosphorus-solubilizing bacteria improved phosphorus uptake and yield.

Advantages

✓ Precision sowing and easy handling
✓ Enhanced nutrient availability and uptake
✓ Longer shelf life of microbial inoculants
✓ Better crop establishment

Seed Fortification

Seed fortification (also called seed enrichment or seed biofortification) is the process of improving the nutrient status of seeds either externally (through soaking/priming) or internally (through genetic methods).

Biotechnological Approaches

Genetic Biofortification: Marker-assisted selection and transgenic approaches are used to develop nutrient-rich seeds.

Example: Golden Rice enriched with Vitamin A, Zinc-enriched wheat, Iron-rich pearl millet.

Seed Priming with Biostimulants: Soaking seeds in solutions containing enzymes, amino acids, and growth regulators to improve metabolism and germination.

Example: Hydro-priming with gibberellic acid enhances early seedling growth.

Nanofortification: Loading seeds with nanoparticles of iron, zinc, or selenium for efficient nutrient delivery.

Example: Nanofortified rice seeds with zinc nanoparticles showed higher yields and stress tolerance.

Microbial Fortification: Use of biofertilizers (e.g., Azotobacter, Rhizobium, Phosphate solubilizers) to enhance nutrient availability in early growth stages.

Advantages

✓ Improved seed nutrient content (iron, zinc, vitamins, etc.).
✓ Faster and uniform germination.
✓ Better tolerance to drought, salinity, and temperature extremes.
✓ Improved human nutrition through biofortified crops.

Conclusion

Biotechnology has transformed traditional seed enhancement practices like coating, pelleting, and fortification into advanced, eco-friendly, and highly efficient techniques. By incorporating beneficial microbes, nanotechnology, and genetic tools, seeds can now be designed for higher vigor, stress tolerance, nutrient richness, and disease resistance. These approaches not only improve agricultural productivity but also contribute to sustainable farming and global food security. Future developments in biotechnology will focus on smart seed technologies where seeds act as delivery systems for nutrients, bio-pesticides, and stress tolerance traits, ensuring climate-resilient and sustainable agriculture.

References

Behera, S. R., Pandey, R., Kalita, R. and Kumar, A. Chapter: 13 Seed Quality Enhancement in Vegetable Crops. *Frontiers in Horticulture Sustainability*, II: 157.

Anitha, M. S., Arunkumar, B. R., Nalini, B. S., Punitha, B. C. and Raju, T. J. (2025). Chapter-7 Micro Boost for Seeds: Enhancing Quality and Longevity with Micronutrients. *Agricultural Biotechnology*, 153.

Kolur, S. M., Burud, A., Ramasamy, M., Sampath, V., Chellem, S. R., Satapathy, S. N. and Rout, A. (2024). A review on biotech innovations in seed technology for robust crop production. *Journal of Advance Biology and Biotechnology*, 27: 535-550.

Panda, D. and Mondal, S. (2020). Seed enhancement for sustainable agriculture: an overview of recent trends. *Plant Archives*, 20(1): 2320-2332.

Genetics of Seed Dormancy and Germination

P. Swathi, S. Subashini and K. Chozhan

Abstract

Seed dormancy and germination are complex traits controlled by a combination of genetic, physiological, and environmental factors. Dormancy ensures survival by preventing germination under unfavorable conditions, while timely germination is essential for seedling establishment and crop productivity. The genetic regulation of these processes involves the interaction of multiple genes, quantitative trait loci (QTLs), and molecular pathways, particularly those related to phytohormones such as abscisic acid (ABA) and gibberellins (GA). Key transcription factors, signaling molecules, and epigenetic modifications also play crucial roles in determining dormancy depth and germination potential. Advances in molecular genetics, genomics, and biotechnology have enhanced our understanding of seed dormancy mechanisms in model plants like Arabidopsis thaliana as well as in cereals and legumes. This knowledge is vital for breeding programs aimed at improving seed quality, uniform germination, and stress resilience in agricultural crops.

Introduction

Seeds act as the primary unit of plant reproduction and survival, bridging the gap between generations and allowing plants to adapt to diverse environmental conditions. Two fundamental and interrelated processes, seed dormancy and germination, determine the successful establishment of plants in natural and agricultural ecosystems. Dormancy is defined as the temporary failure of viable seeds to germinate even under favorable conditions, serving as an adaptive strategy against environmental unpredictability. In contrast, germination represents the resumption of metabolic activity leading to radicle protrusion and seedling establishment.The regulation of these traits is under strong genetic control, with multiple loci influencing seed development, hormone balance, and stress responses. Abscisic acid (ABA) promotes dormancy, whereas gibberellins (GA) stimulate germination, and the balance between these hormones is genetically regulated by biosynthesis and signaling genes. In addition, transcription factors such as ABI3, DOG1, FUS3, and LEC1 play essential roles in establishing and maintaining dormancy. Recent research has also highlighted the importance of epigenetic mechanisms such as histone modification

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and small RNAs, in fine-tuning dormancy and germination pathways.Understanding the genetics of seed dormancy and germination has significant implications for agriculture, particularly in crop species where pre-harvest sprouting, uneven germination, or poor seed vigor affect yield and quality. With the advent of genomic tools, transcriptomics, and genome editing technologies, new opportunities have emerged to manipulate seed traits for enhanced agricultural performance.

Types of Seed Dormancy

Primary Dormancy: Established during seed development on the mother plant; prevents immediate germination.

Secondary Dormancy: iInduced after seed dispersal if conditions are unfavorable.

Physiological Dormancy: Controlled by hormonal balance (mainly ABA and GA).

Physical Dormancy: Caused by impermeable seed coat (common in legumes).

Morphological Dormancy: Embryo is under-developed at dispersal.

Morphophysiological Dormancy: Combination of structural and physiological constraints.

Example

- ✓ Wheat (*Triticum aestivum*) → dormancy prevents PHS.
- ✓ Arabidopsis (*Arabidopsis thaliana*) → extensi-vely studied model for genetic control of dormancy.
- ✓ Legumes like *Cajanus cajan* (pigeon pea) → hard-seededness due to physical dormancy.

Genetic Regulation of Seed Dormancy

Hormonal Regulation (ABA Pathway): Abscisic Acid (ABA) is the central hormone inducing and maintaining dormancy.

Key genes

NCED6 and NCED9: ABA biosynthesis during seed maturation.

ABI3, ABI4, ABI5: Transcription factors that enforce dormancy by activating ABA-responsive genes.

DOG1 (Delay of Germination 1): Major dormancy gene discovered in Arabidopsis; controls dormancy depth and duration across species.

Epigenetic Regulation

DNA methylation and histone modifications regulate dormancy genes.

Example: DOG1 expression is controlled by histone methylation (H3K27me3). Small RNAs (siRNAs/ miRNAs) also fine-tune gene expression.

Maternal Effects

The genotype of the mother plant influences seed dormancy.Maternal ABA levels regulate embryo development and dormancy induction.

Genetic Regulation of Germination

Hormonal Regulation (GA Pathway): Gibberellins (GA) promote germination by counteracting ABA.

Key genes

GA20ox and GA3ox: GA biosynthesis enzymes.

GA2ox: GA degradation enzyme (suppresses germination).

RGL2 (a DELLA protein): Represses germination; degraded when GA levels rise.

Light Regulation: Phytochromes (PHYs) sense red/far-red light to trigger germination. PIF1 represses germination in the dark; degraded under light, enabling GA action.

Cell Wall Modification: Genes encoding expansins, endo-β-mannanases and xyloglucan endotransglucosylases promote radicle protrusion by loosening the seed coat.

ABA Catabolism: CYP707A genes degrade ABA, lowering dormancy and allowing germination.

Environmental and Genetic Interactions

Temperature: High temperatures can break dormancy (thermodormancy).

Light: Phytochromes integrate light signals into hormonal pathways.

Oxygen and Moisture: Hypoxia delays germination by reducing energy metabolism.

Nitrate: Serves as both a nutrient and a signaling molecule to stimulate germination by repressing ABA signaling.

Applications in Agriculture

Preventing Pre-Harvest Sprouting (PHS): Strengthening dormancy genes (DOG1, ABI5) in cereals like wheat and barley.

Uniform Germination: Targeting GA biosynthesis genes for synchronized crop establishment.

Seed Longevity and Storage: Understanding dormancy genes aids in maintaining seed viability in gene banks.

Climate Resilience: Engineering crops with adaptive dormancy traits to cope with fluctuating environments.

Marker-Assisted Selection (MAS): Use of dormancy-related QTLs (Quantitative Trait Loci) in breeding programs.

Recent Advances

- ✓ CRISPR-Cas9 gene editing to manipulate DOG1 and ABA-related genes.
- ✓ QTL mapping and GWAS (Genome-Wide Association Studies): Identified dormancy loci in wheat, rice, and barley.
- ✓ Transcriptomics and Proteomics: Help in discovering novel dormancy regulators.
- ✓ Synthetic Biology Approaches: Designing artificial promoters for dormancy control.

Conclusion

Seed dormancy and germination are complex traits regulated by an intricate genetic network involving hormonal crosstalk, transcriptional control, and environmental signals. ABA and GA form the central hormonal axis, with key regulators such as DOG1, ABI3, and RGL2 controlling the balance between dormancy and germination. Advances in molecular genetics, genomics, and biotechnology provide new opportunities for breeding crops with optimal seed performance. A thorough understanding of these processes is essential to improve agricultural productivity, prevent pre-harvest sprouting, and ensure global food security.

References

Koornneef, M., Bentsink, L. and Hilhorst, H. (2002). Seed dormancy and germination. *Current Opinion in Plant Biology*, 5(1):33-36.

Foley, M. E. (2001). Seed dormancy: an update on terminology, physiological genetics, and quantitative trait loci regulating germin-ability. *Weed Science*, 49(3): 305-317.

Bentsink, L. and Koornneef, M. (2008). Seed dormancy and germination. *The Arabidopsis Book/ American Society of Plant Biologists*, 6:e0119.

Nonogaki, H. (2014). Seed dormancy and germination emerging mechanisms and new hypotheses. *Frontiers in Plant Science*, 5: 233.

Seed Drying: Importance, Methods and Applications

Sibivarman, S. Subashini and Cholan

Abstract

Drying seeds yeah, it's not exactly the sexiest topic, but wow does it matter. If you mess it up, you're looking at moldy, bug-infested, useless seed piles. Get it right, though, and you've got seeds that can chill in storage for ages, staying viable and ready for action. This piece dives into why seed drying matters so much, how it works (spoiler: it's not just about leaving them in the sun), and what it means for anyone who actually wants plants to grow from their seeds in the future.

Introduction

Seeds aren't just tiny rocks you toss in the ground and forget about. They're alive. They breathe, they've got moisture inside, and if you stick them in storage all swampy, they'll go bad faster than week-old bread in July. High moisture? That's a VIP invite for fungus and bugs nobody wants that. That's why you've got to dry them out to the sweet spot. Most "normal" seeds (the technical term is "orthodox," but whatever) like to be at about 8-10% moisture. Some diva seeds (recalcitrant ones) freak out if you dry them too much, so it's a balancing act. At the end of the day, drying seeds right is the backbone of seed tech and farming it keeps seeds alive, pure, and ready to grow when you need them.

Why Bother Drying Seeds?

Keeps Seeds Alive: Less moisture means less breathing and slower aging.

Longer Shelf Life: Dry seeds hang around for years without turning to dust.

Stops Mold & Bugs: Fungi and insects aren't fans of dry conditions.

Makes Moving Seeds Easier: Drier = lighter. Shipping's cheaper, handling's less of a pain.

Follows the Rules: Seed certification folks are picky. They want seeds at the right dryness.

How Seed Drying Actually Works

The goal is simple: get rid of enough water so the seeds stay alive and healthy, but don't fry their insides. A few things matter:

Temperature: Too hot? You'll cook the seeds. Not good.

Humidity: Seeds adjust to the air around them, so if it's muggy, good luck drying.

Airflow: Gotta keep the air moving, or you'll get pockets of soggy seeds.

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Seed Type: Corn isn't beans, and beans aren't peanuts each needs its own moisture target.

Ways People Dry Seeds (For Real)

Sun Drying: The old-school method. Spread seeds out on some tarp, hope the weather cooperates, and cross your fingers. Cheap, but you're at the mercy of rain, birds, and whatever else nature throws at you. Uneven drying is a pain.

Natural Air Drying: Just let the breeze do its thing. Works best if the air's already dry. Takes a while, though so don't be in a rush.

Heated Air Dryers: Now we're getting fancy. Machines blow warm air over seeds (not too hot, though). You've got batch dryers, flat-bed dryers, all sorts. Fast, even, reliable but costs a pretty penny.

Dehumidified Air: If you live somewhere that feels like a sauna, regular air drying's a joke. These setups suck moisture out of the air before blowing it over your seeds. Not cheap, but super effective in sticky climates.

Low-Temperature Drying: Used for the good stuff breeder or foundation seeds. Keeps them alive for years, but you'll need some serious equipment.

Safe Moisture Levels (Don't Guess)

- ✓ Cereals (wheat, rice, maize): 8-10%
- ✓ Pulses (chickpeas, lentils): 7-9%
- ✓ Oilseeds (soybean, sunflower): 5-7%
- ✓ Veggie seeds: 6-8%

Drying Isn't Always a Walk in the Park

Some seeds are drama queens dry them a bit too much, and they're done for. Mechanical dryers? Not exactly budget-friendly for the average farmer. And getting every seed in a giant pile evenly dry? Harder than it sounds.

Where it all Matters

Seed Banks: Want to save seeds for decades? Drying's non-negotiable.

Certification: You gotta hit those moisture targets or your seeds aren't going anywhere.

Hybrid Seeds: Uniform quality means drying them right, every time.

Farming: Good, dry seeds = better crops. Duh.

Wrap-Up: Honestly, if you're ignoring seed drying, you're basically playing Russian roulette with your entire crop. Drying right means you keep seeds alive, healthy, and ready for whatever the world throws at them. Sure, you can lay them out in the sun like your grandma did, but if you want precision, those fancy dryers can't be beat. Somewhere in the middle? Probably the smart move, especially with climate getting weirder every year and food demand going up. Bottom line: treat your seeds right, and they'll return the favor.

References

Bewley, J. D., Bradford, K. J., Hilhorst, H. W. and Nonogaki, H. (2013). Seeds: Physiology of development, germination and dormancy. Springer.

Copeland, L. O. and McDonald, M. B. (2012). Principles of seed science and technology. Springer Science & Business Media.

Ellis, R. H. and Roberts, E. H. (1980). Improved equations for the prediction of seed longevity *Annals of Botany*, 45(1): 13-30.

Precision Farming: The Future of Agronomy

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Abstract

Precision Farming is defined as information and technology based farm management system to identify, analyse and manage spatial and temporal variability within fields for optimum productivity and profitability, sustainability and protection of the land resources by minimizing the production costs. Precision farming is transforming the landscape of modern agriculture by integrating advanced technologies. Precision farming is revolutionizing agronomy by integrating technology with traditional agricultural practices. By using data-driven tools like GPS, drones, soil sensors, and AI, farmers can optimize crop yield, reduce input costs, and ensure sustainable resource use. It explores how precision farming is transforming agronomic practices and shaping the future of agriculture. It allows farmers to make informed decisions to improve productivity, reduce costs, and promote sustainable agriculture. As agronomy moves toward greater efficiency and environmental consciousness, precision farming stands as a key innovation for the future.

Introduction

Agronomy, the science of crop production and soil management, has traditionally relied on uniform field treatments and manual practices. However, challenges like climate change, limited resources, and the need for higher productivity have made traditional methods less effective. This is where precision farming, also known as smart farming, is playing a revolutionary role. The conventional farming systems has led to extensive usage of agricultural inputs like machinery, pesticides, water, and other inputs resulting in negative environmental impacts such as pollution of the environment by emission of greenhouse gases. Research suggests educational and economic challenges as the two most important in the application of precision agriculture. Precision farming involves using modern technologies such as Global Positioning Systems (GPS), Geographic Information Systems (GIS), remote sensors, drone imaging, Artificial Intelligence (AI), and Internet of Things (IoT) to collect field data. This data helps farmers apply inputs like water, fertilizers, and pesticides precisely only where and when they are needed. This technology-driven approach is helping transform agronomy into a more efficient, profitable, and environmentally friendly science. Precision farming involves collecting real-time data about soil, weather, crops, and other environmental conditions to make informed decisions. It allows for:

- ✓ Variable rate application of fertilizers, water, and pesticides

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- ✓ Soil health monitoring using sensors
- ✓ Drones and satellite imagery to assess crop health
- ✓ GPS-enabled machinery for accurate sowing and harvesting
- ✓ Data analytics and AI to predict yields and diagnose issues

Five "R's" of Precision Farming

Robert *et al*. (1994) proposed three -R's, the Right time, the Right amount and the Right place. Later, the International Plant Nutrition Institute added another -R' to that list, -the Right Source‖, and more recently, Khosla (2008) proposed an additional -R', the Right manner.

The right source: The right source of nutrient is not of grave concern since that has been identified and established for a long time. However, in the dynamic world of precision nutrient management, where the machine based decision is made in -real-time, it becomes imperative that we must realize the limiting nutrient(s) and adequately address the need with the correct source.

The right place: since inception of precision agriculture -the right place‖ aspect has received the most attention by scientists and practitioners. There are a number of sampling techniques and designs that allow us to characterize and quantify the scale and pattern of spatial variability in fields, such as grid soil sampling, site-specific management zones, smart sampling, soil electrical conductivity measurements, etc. However, we still need an economically feasible technique of quantifying the spatial variability in soil and crop properties at a scale that exists in the heterogeneous fields.

The right time: Availability of active remote-sensors, that can be mounted on high clearance fertilizer applicators has coupled the technology of mapping variability in the crop canopy‖ and variably applying fertilizer, simultaneously in real-time.

The right amount: After the advent of precision technologies, the right amount of nutrient to be applied across spatially variable fields was initially accomplished by utilizing existing nutrient recommendation algorithms developed by the research and academic institutions / Universities.

The right manner: in precision nutrient management, -Right manner refers to the method of placement of nutrient in the soil, (i.e.) broadcast versus banding, dribbling, injecting, etc. The -right manner, aspect may be not be very important for agriculture practiced in the developed world, however, it is of great importance for global precision agricultural practices.

Benefits of Precision Farming

Increased efficiency: By optimizing resource use and tailoring practices to specific needs, precision farming helps reduce waste and improve resource efficiency.

Improved sustainability: Reducing input use and minimizing environmental impacts contribute to more sustainable agricultural practices.

Enhanced crop yields: By providing crops with the optimal inputs they need, precision farming can help increase yields and overall productivity.

Reduced costs: Efficient resource use & optimized practices can help reduce farming costs, such as fertilizer and pesticide expenses.

Environmental protection: Precision farming helps minimize chemical runoff, reduces water waste, and preserves soil health, contributing to environmental protection.

Key Aspects of Precision farming

The precision farming mainly depends on three key aspects. They are:

Information: Is one of the important key aspects in precision farming as it mainly deals with the various aspects of spatial and temporal variability data on which the management decisions depend.

Technology: It comprises the use of technologies like GPS, GIS, remote sensing etc., to acquire knowledge on various aspects of crop and land parameters.

Management: It comprises the management decisions to manage the variability.

New Tools and Technologies

Remote sensing and GIS Mapping: For land use planning and monitoring.

Soil Mapping and Testing Kits: Determine nutrient status and texture.

Crop Simulation Models: Predict crop growth and yield under various scenarios.

Artificial Intelligence: For disease detection, irrigation planning, and forecasting.

Mobile Apps and Farm Management Software: Help farmers make real-time decisions.

Constraints in adoption of Precision farming

The constraints in adoption of precision farming technologies in India are:

- ✓ Small size of land holding
- ✓ High cost of investment
- ✓ Highly skilled labour requirement
- ✓ Lack of training programs
- ✓ Complexity of tools and techniques requiring new skills
- ✓ Lack of local technical expertise
- ✓ Heterogeneity of cropping systems and market imperfections
- ✓ Inadequate knowledge about PF among the farmers
- ✓ Assured availability of quality seed or planting material of desired crop and variety.

Maharashtra, India: Farmers using soil health cards and drip irrigation boosted cotton yields by 20%.

Punjab, India: Precision nutrient management in wheat farming saved 30% urea with equal or better yield.

Conclusion

Precision farming is not just a trend; it is a necessary evolution in agronomy. With its ability to enhance yields, reduce environmental impact, and optimize input use, it paves the way for sustainable agricultural development. For a country like India, where agriculture is the backbone of the economy, adopting precision farming can revolutionize rural livelihoods. Educating farmers, making technology affordable, and building robust digital infrastructure will be key to realizing the full potential of this modern agronomic approach. The integration of science, technology, and agronomic principles will define the next green revolution.

References

Dama, V. R., Singh, J. P., Sharma, S., Khar, S. and Shrivastava, R. K. (2020). Scope and adoption of precision farming in India. *Agricultural & Environment ENewsletter*, 1 (3): 104-107.

FAO. Precision agriculture and the future of farming. Food and Agriculture Organization of the United Nations.

ICAR - Indian Council of Agricultural Research. (https://icar.org.in/)

Jha, S. K. *et al*. (2020). Precision Agriculture: An Emerging Technology for Indian Agricu-lture. *Indian Farming Magazine.*

Dixit, J., Dixit, A. K., Lohan, S. K. and Kumar, D. Importance, Concept and Approaches for Precision Farming in India. *Academia*, 12-35.

Khosla, R. (2010). Precision agriculture: challenges and opportunities in a flat world. Paper presented in: 19th World Congress of Soil Science, Soil Solutions for a Changing World, Brisbane, Australia. August 1-6, pp: 26-28.

Robert, P. C., Rust, R. H. and Larson, W. E. (1995). In proceedings of site specific management for agriculture system, 27-30 March 1994, Minneaports, MN, ASACSSASSA, Madison pp: 13-14.

CRISPR-Cas 9 and its Future in Agriculture

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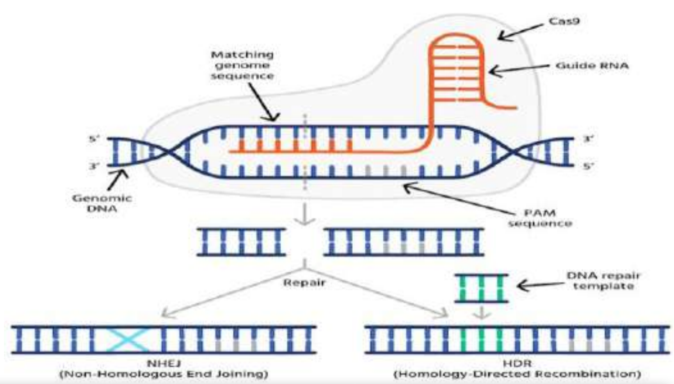
Abstract

CRISPR-Cas9 is a modern gene-editing tool that allows scientists to precisely change the DNA of plants. It acts like molecular scissors, helping crops grow better and resist diseases, pests, and harsh weather. In agriculture, CRISPR is used to develop drought-tolerant plants, improve nutritional value, and reduce the need for chemical fertilizers and pesticides. This technology can make farming faster, more efficient, and environmentally friendly. Although challenges like regulations, ethics, and public acceptance remain, CRISPR-Cas9 holds great promise for the future of agriculture. With careful research and responsible use, it can help produce healthier crops, increase yields, and ensure sustainable food production for a growing global population.

Introduction

CRISPR-Cas9 is a modern gene-editing tool that allows precise changes in plant DNA. In agriculture, it helps develop crops that resist diseases, pests, and harsh weather. This technology can improve crop yield, nutrition, and reduce the need for chemicals. CRISPR-Cas9 offers a faster, smarter, and sustainable way to meet the growing global food demand.

CRISPR -Cas 9: CRISPR-Cas9 is a gene-editing technology that allows scientists to precisely change the DNA of living organisms. CRISPR (Clustered Regularly Interspaced Short Palindromic Repeats) works with the Cas9 protein, which acts like molecular scissors to cut DNA at a specific spot. First, they select the gene they want to modify and design a small guide RNA that matches this gene. The Cas9 protein, along with the guide RNA, is introduced into the cell. Cas9 acts like molecular scissors and cuts the DNA at the target site. The cell then repairs the cut, allowing scientists to remove, add, or change the gene. Finally, scientists check the cells to ensure the desired changes have occurred. This method is faster, more accurate, and simpler than traditional breeding techniques.



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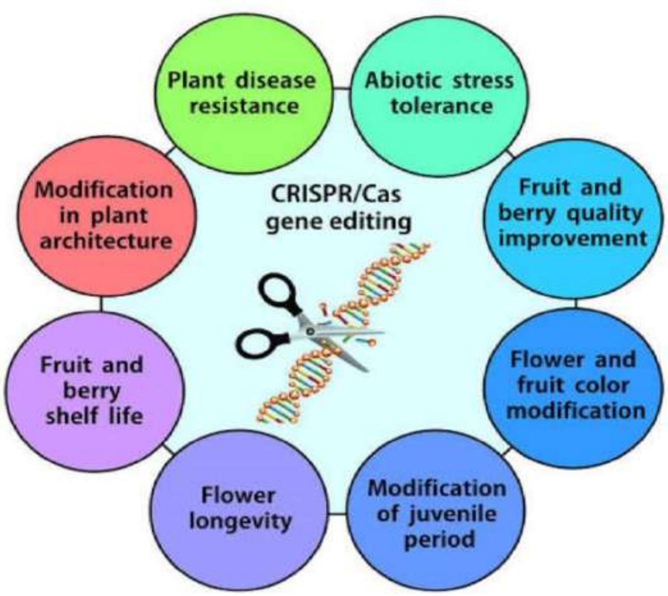
Application in agriculture: In agriculture is developing disease-resistant crops. Many plants are affected by viruses, bacteria, or fungi, which can destroy entire harvests. With CRISPR, scientists can edit the genes of crops so they naturally resist these diseases. For example, rice, wheat, and tomatoes can be made resistant to major pests and diseases, reducing the need for chemical pesticides. Important is improving crop yield and quality. Farmers need more food for a growing population, but climate change makes farming harder. CRISPR can help create plants that grow faster, use water more efficiently, and survive extreme weather like drought or heat. It can also improve the nutritional content of crops, making fruits and vegetables healthier for consumers. It is also promising in livestock farming. Scientists are exploring ways to edit the genes of animals to make them more resistant to diseases, grow faster, or produce healthier meat and milk. This could improve food security while reducing the environmental impact of farming.



It may help in sustainable agriculture. By creating crops that need less water, fertilizer, or pesticides, we can protect natural resources and reduce pollution. This technology could play a key role in producing enough food without harming the planet.

Conclusion

CRISPR-Cas9 is revolutionizing agriculture by enabling precise gene editing. It helps develop disease-resistant, high-yield, and climate-resilient crops, improves livestock traits, and promotes sustainable farming. With careful use, this technology can ensure food security, enhance nutrition, and support eco-friendly farming practices for the growing global population.

References

Clarke, J. L. and Zhang, P. (2013). Plant biotechnology for food security and bioeconomy. *Plant Molecular Biology*, 83 (1): 1-3.

FAOSTAT. [Online]. Available: http://www.fao.org /faostat/en/#home[Accessed: 07-May-2019].

Stamm, P., Ramamoorthy, R. and Kumar, P. P. (2011). Feeding the extra billions: strategies to improve crops and enhance future food security. *Plant Biotechnology Reports*, 5(2): 107-120.

Alogaz, Y., Gurkok, T., Zhang, B. and Unver, T. (2016). Manipulating the biosynthesis of bioactive compound alkaloids for next-generation metabolic engineering in opium poppy using CRISPR-Cas 9 genome editing technology. *Scientific Reports*, 6: 30910.

Andersson, M., Turesson, H., Nicolia, A. *et al.* (2017). Efficient targeted multiallelic mutagenesis in tetraploid potato (*Solanum tuberosum*) by transient CRISPR-Cas9 expression in protoplasts. *Plant Cell Reports*, 36: 117-128.

Armengaud, P., Sulpice, R., Miller, A. J. *et al*. (2009). Multilevel analysis of primary metabolism provides new insights into the role of potassium nutrition for glycolysis and nitrogen assimilation in Arabidopsis roots. *Plant Physiology*, 150: 772-785.

Kim, D. (2017). Genome-wide target specificities of CRISPR RNA-guided programmable deaminases. *Nature Biotechnology*, 35(5): 475-480.

Rees, H. A. (2017). Improving the DNA specificity and applicability of base editing through protein engineering and protein delivery. *Nature Communications*, 8: 15790.

Voth, D. E., Broederdorf, L. J. and Graham, J. G. (2012). Bacterial Type IV secretion systems: versatile virulence machines. *Future Micro-biology*, 7(2): 241-257.

Seed Hardening in Green Gram

M. Jeyashree, S. Subhashini and K. Chozhan

Abstract

Seed hardening is a low-cost, eco-friendly pre-sowing treatment that enhances seed performance under stress conditions. In green gram (*Vigna radiata*), seed hardening improves germination, seedling vigor, drought tolerance, and overall yield. This article highlights the importance, techniques, and benefits of seed hardening, along with its impact on yield improvement. Recent studies have shown that treating seeds with water or osmotic solutions such as polyethylene glycol, potassium chloride, or plant growth regulators improves field performance. Thus, seed hardening is an important strategy for sustainable pulse production in rainfed regions.

Introduction

Green gram (*Vigna radiata*), commonly known as mung bean, is an important short-duration pulse crop rich in protein and micronutrients. It plays a vital role in Indian agriculture due to its adaptability to diverse agro-climatic conditions and its ability to fix atmospheric nitrogen. However, yield levels are often constrained by abiotic stresses such as drought, salinity, and irregular rainfall. Seed hardening is a simple pre-sowing technique where seeds are treated with water or chemical solutions, then dried back to their original moisture content before sowing. This process physiologically prepares seeds to withstand stress and enhances early establishment. Seed hardening has proven effective in green gram to improve germination percentage, seedling vigor, and yield, especially under rainfed conditions.

Importance and Benefits of Seed Hardening: Seed hardening plays an important role in improving the performance of green gram under field conditions. It ensures early and uniform germination by enabling the seed to imbibe water efficiently. Hardened seeds develop into vigorous seedlings with longer roots and shoots, which helps in better nutrient and water uptake. One of the major advantages of hardening is that it increases tolerance to drought, salinity, and other stresses, thereby reducing seedling mortality. In legumes like green gram, it also enhances nodulation by supporting better symbiotic activity with Rhizobium, leading to improved nitrogen fixation. Moreover, hardened seeds contribute to stable yields even under fluctuating climatic conditions. As the technique requires minimal input

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and is economical, it is considered highly farmer-friendly and a sustainable method to increase productivity in pulse crops.

Techniques Used in Seed Hardening: Several techniques are employed in seed hardening. The simplest and most widely used method is hydro-priming, where seeds are soaked in water for 6-8 hours and then dried back to their original moisture content. Chemical hardening involves the use of osmotic or salt solutions such as potassium chloride (KCl), calcium chloride ($CaCl_2$), zinc sulfate ($ZnSO_4$), or potassium dihydrogen phosphate (KH_2PO_4), which induce stress tolerance in seeds. Hormonal priming is another method where plant growth regulators like gibberellic acid (GA_3), salicylic acid, or ascorbic acid are used to enhance germination and stress resistance. Osmopriming with polyethylene glycol (PEG) helps regulate the water absorption rate and improves seedling performance under stress. Biopriming with beneficial microbes such as Rhizobium or Trichoderma spp. is also practiced to improve germination, nodulation, and resistance against soil-borne diseases. These techniques help the crop to withstand adverse conditions and ensure better establishment in the field.

Yield Improvement through Seed Hardening: Seed hardening significantly improves the yield potential of green gram. Hardened seeds germinate faster and more uniformly, producing vigorous seedlings that establish well in the field. This early establishment leads to stronger plants with enhanced root and shoot growth, which results in better nutrient and water uptake. Hardened seeds also show greater tolerance to drought, salinity, and temperature fluctuations, ensuring survival and growth even under stress conditions. In addition, nodulation is improved when seeds are bioprimed with Rhizobium, leading to higher nitrogen fixation and biomass production. Overall, these advantages translate into higher pod numbers and grain yield. Studies conducted at Tamil Nadu Agricultural University have shown that green gram seeds hardened with 1% KCl solution recorded higher germination, more pods per plant, and significantly improved yields under rainfed conditions. Research indicates that seed hardening can increase green gram yield by 10-20%, making it a valuable technique for pulse farmers.

Conclusion

Seed hardening is an effective, low-cost, and farmer-friendly technology to enhance the performance of green gram under variable climatic conditions. By improving germination, vigor, stress tolerance, and yield, this technique plays a crucial role in sustainable pulse production. Adoption of seed hardening at the farm level can ensure stable yields and contribute to food security in rainfed areas. Future research should focus on integrating hardening techniques with other agronomic practices for maximizing productivity.

References

Varier, A., Vari, A. K. and Dadlani, M. (2010). The subcellular basis of seed priming. *Current Science*, 99(3): 450-456.

Basra, S. M. A., Farooq, M. and Tabassum, R. (2005). Physiological and biochemical aspects of seed vigor enhancement treatments in fine rice (*Oryza sativa*). *Seed Science and Technology*, 33: 623-628.

Kumar, R., Singh, G. and Singh, R. (2014). Effect of seed priming on germination and seedling vigor in mung bean (*Vigna radiata* L.). *Journal of Food Legumes*, 27(2): 160-163.

Sathya, V. and Ramesh, T. (2019). Influence of seed hardening techniques on germination and yield of green gram (*Vigna radiata*). *International Journal of Current Micro-biology and Applied Sciences*, 8(3): 212-220.

TNAU Agritech Portal (2021). Seed hardening techniques for pulses. Tamil Nadu Agricultural University.

DNA Structure and Its Role in Heredity

Saradhasekar, Subashini K. and K. Chozan

Abstract

Seed hardening is a low-cost, eco-friendly pre-sowing treatment that enhances seed performance under stress conditions. In green gram (*Vigna radiata*), seed hardening improves germination, seedling vigor, drought tolerance, and overall yield. This article highlights the importance, techniques, and benefits of seed hardening, along with its impact on yield improvement. Recent studies have shown that treating seeds with water or osmotic solutions such as polyethylene glycol, potassium chloride, or plant growth regulators improves field performance. Thus, seed hardening is an important strategy for sustainable pulse production in rainfed regions.

Introduction: The Mystery behind Family Resemblance

Do you ever pause to consider the fact that families tend to share a "signature look"? Perhaps it's your grandfather's unruly hair, your mother's smile, or your dad's height that crops up in you. These similarities within the family seem almost like magic, but they have scientific basis. The key is DNA, the molecule that contains and passes on instructions for life. All living things on our planet, from bacteria to elephants, use DNA to carry its specific biological blueprint. Without it, there would be no heredity, no passing of characteristics, and no life as we know it. What is so interesting about DNA is not just its capacity for replicating itself with incredible precision but its capacity to provide diversity as well. Each individual's DNA is 99.9% identical to that of any other human, and yet the infinitesimal part that varies is adequate to render us all different from one another. That is why twins may resemble each other but are not the same, and why identical twins themselves accumulate differences as the years go by. Knowing DNA provides us a preview of why families are alike and why no two people are the same. It is the biological string that connects the generations.

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The famous double helix structure of DNA, discovered by James Watson, Francis Crick, and Rosalind Franklin, looks like a twisted ladder that stores life's instructions.

What is DNA? The blueprint of Life

DNA stands for deoxyribonucleic acid and is commonly referred to as the blueprint of life, and rightly so. Think of an enormous instruction book composed of a four-letter alphabet A, T, C, and G. These abbreviations represent adenine, thymine, cytosine, and guanine, the four chemical building blocks of DNA. Linked together in innumerable combinations, these bases are the recipes for all the proteins in your body, from the oxygen-carrying hemoglobin in your blood to the digestive enzymes that break down your food. It is DNA's universality that makes it so astounding. The fruit fly, the whale, and the human all employ the same chemical bases and demonstrate that life on Earth is strongly interconnected. Humans actually share the DNA of cabbages for approximately 50% and of chimpanzees for approximately 98%. Such a shared code demonstrates how evolution changed and recycled DNA's instructions to create the vast variety of life. DNA isn't scattered willy-nilly throughout our bodies. It is compacted tightly into buildings known as chromosomes, and each regular human cell has 46 of them 23 pairs, one from each parent. All together, these chromosomes contain approximately 20,000-25,000 genes, each instructing different characteristics or biological activities. Without DNA's complex instructions, cells would have no idea how to grow, reproduce, and exist.

The Double Helix: Nature's Twisted Ladder

DNA's design is as beautiful as it is utilitarian. James Watson and Francis Crick, with the key inputs of Rosalind Franklin's X-ray photographs, revealed DNA's iconic double helix structure in 1953. Imagine a spiral staircase of a ladder: the rungs are composed of sugar and phosphate molecules, and the steps are two nitrogenous bases A and T, and C and G. This specific combination is the source of DNA's stability and capacity to reproduce.

Why is this shape so important? The double helix enables DNA to contain an enormous amount of information in a very small space. If all the DNA in one human cell were uncoiled, it would be almost two meters long but fits within a nucleus that is merely a few micrometers in diameter. Divide that by your body's approximated 37 trillion cells, and you've got enough DNA to stretch from Earth to the Sun and back and forth hundreds of times!

The coiled ladder also allows that when DNA is replicated during cell division, the process is nearly error-free. Each strand acts as a template for building its partner strand, so that genetic information is passed on reliably. The reliability of heredity is maintained by this accuracy, but small, sporadic errors mutations drive evolution and diversity.

How DNA Transfers Traits from Parents to Children

Heredity is the mechanism for transmitting characteristics from one generation to the next, and

DNA is the vehicle for carrying this important information. When a baby is born, it receives half of its DNA from the mother's egg and half from the father's sperm. Together, these inputs create a new genetic map, resulting in an individual who is connected to but unique from both parents. The process of inheritance is not merely copy-paste. Prior to eggs and sperm being produced, an operation known as recombination rearranges patches of DNA between the paired chromosomes. Imagine shuffling two decks of cards to produce distinct hands. This shuffling guarantees that even siblings from the same parents inherit slightly varied sets of characteristics. Some characteristics, such as blood type, are the result of single genes. Others, such as height, skin color, or intelligence, are the result of many genes acting together, and often influenced by the environment. Mutations tiny changes in DNA can be inherited, occasionally producing genetic disorders, but also giving rise to diversity. In the absence of these variations, evolution would not be possible, and species would be unable to adapt to a changing world. Heredity is therefore both a process of stability and a source of infinite variation.

Each child receives half of their DNA from the mother and half from the father, creating a unique genetic combination that explains family resemble-nce and individuality.

Why We qre Similar Yet Unique

It's a joke that children are a combination of their parents, but no two individuals except for identical twins are identical. The reason is the intriguing interplay of genetic likeness and uniqueness. Humans share 99.9% of their DNA on average, but the 0.1% is responsible for the rich diversity of differences we witness in looks, behavior, and disease susceptibility. Genetic variation has a number of causes. Recombination mixes up genetic material when gametes form, generating an infinite number of combinations of parental traits. Mutations, while infrequent, add novel genetic “spelling alterations” that might change traits or even give rise to entirely new ones. And while alleles, various forms of the same gene, specify variations such as blue versus brown eyes. But DNA is not the entire story. The environment contributes in a formidable way as well. Identical twins brought up in different environments might develop faint personality, health, and even physical differences. Over and above that, new research into epigenetics indicates that chemical tags can turn genes on or off based on lifestyle and environment. Such changes can sometimes be transmitted to future generations, another layer of heredity. This blending of sameness and difference accounts for the way that you can inherit your grandmother's dimples but be otherwise the unique individual that you are.

Conclusion: DNA, the Universal Code of Life

DNA is the strand that binds all living organisms together. It holds the blueprints for life, verifies characteristics are inherited through heredity, and simultaneously provides room for diversity and uniqueness. Its form the beautiful double helix assures fidelity in duplication, while its infrequent mistakes drive evolution and adaptation. Now, our knowledge of DNA extends far beyond the classroom walls. From cracking crimes and tracing ancestry to engineering new medicines and saving digital information, DNA science keeps redefining science and society. It is both a family tale, telling you why you look like your relatives, and a cosmopolitan one, linking you to all other creatures on this planet. Fundamentally, DNA is not just the blueprint of existence but the link between generations and species as well. It is the greatest storyteller writing, holding, and reinventing the epic of life over two billion years.

References

Watson, J. D. (1968). The double helix: A personal account of the discovery of the structure of DNA. *Atheneum.*

National Research Council. (1972). DNA - Structure and function. In Heredity and Development: Second Edition. The National Academies Press.

Genetic Science Learning Center. (2016, March 1). What is inheritance? Learn Genetics. https://learn.genetics.utah.edu/content/basics/inheritance/

Fincham, J. R. S. (2020, August). Recombination (genetics). Access Science. https://www.accessscience.com/content/article/a575500

Stapley, J., Birkhead, T. R., Burke, T. and Slate, J. (2017). Recombination: The good, the bad, and the variable. *PLOS Biology*, 15(11): e2004466.

Bowater, R. P. (2003). DNA structure. In Encyclopedia of Human Genetics. Wiley.

McRae, A. F., Powell, J. E. and Visscher, P. M. (2014). Contribution of genetic variation to transgenerational epigenetic inheritance. *PLOS Genetics*, 10(5): e1004400.

Genetic Purity and Seed Isolation Techniques

C. V. Srijeyabhuvaneswaran, S. Subhashini and K. Chozhan

Abstract

Genetic purity of seed is the key factor for successful crop production and high yield. Pure seed ensures that plants express the true characteristics of a variety or hybrid, such as uniform growth, quality, and market value. However, genetic purity can be lost through cross-pollination, mechanical mixtures, mutations, and improper handling. To maintain purity, various seed isolation techniques are followed. These include maintaining isolation distance between fields, using barrier crops, practicing time isolation to avoid overlapping flowering, removing off-type plants (roguing), and applying controlled pollination methods. By adopting these practices, farmers and seed producers can safeguard seed quality, increase productivity, and contribute to food security.

Introduction

Seed is the most important input in agriculture and is often called the "soul of farming." The success of any crop mainly depends on the quality and purity of the seed used. Genetic purity means that the seed remains true to its type, expressing the exact characters of the variety or hybrid without unwanted changes. Pure seeds give uniform plants, higher yield, and better quality produce. However, seed purity can be affected by factors like cross-pollination with other varieties, mechanical mixtures during handling, or the presence of off-type plants in the seed field. To prevent this, different seed isolation techniques are practiced, such as maintaining isolation distance, using barrier crops, adopting time isolation, roguing, and controlled pollination. These techniques ensure that the seed retains its genetic purity and provides consistent performance in the farmer's field. Thus, maintaining genetic purity through proper isolation techniques is essential for sustainable agriculture, seed certification, and food security.

Genetic Purity

Genetic purity: Seed should be exactly the same as the original variety or hybrid. Example: If you buy seeds of "Hybrid Brinjal," every plant should give the same kind of brinjal (same shape, size, and taste). If the seed is not pure, then:

- ✓ Some plants may look different,
- ✓ Yield will be low,
- ✓ Farmers will lose money.

Pure seeds = more yield, good quality, more profit.

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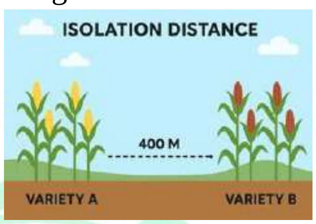
Purity Lost: Seeds can lose purity because of:

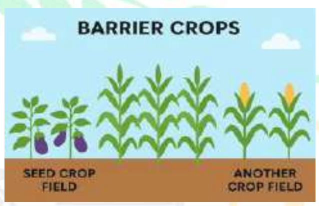
- ✓ Cross-pollination pollen from another variety mixes.
- ✓ Mixing during sowing, harvesting, or storage.
- ✓ Mutations rare natural changes in plants
- ✓ Poor handling careless storage or transport.

Seed Isolation Techniques

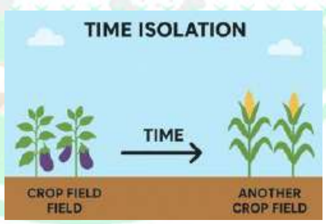
Isolation Distance: Keep enough distance between two varieties of the same crop. Example: For maize, at least 400 meters away from another maize field.



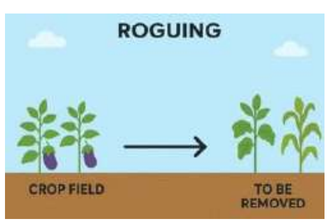
Barrier Crops: Plant tall crops (like sorghum or sunflower) around the seed field. They block pollen movement.



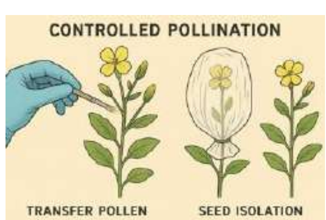
Time Isolation: Plant two varieties at different times so that they flower at different periods. Example: If one variety flowers in January, sow another to flower in February.



Roguing: Remove unwanted or "odd-looking" plants from the seed field. This prevents them from mixing with pure plants.



Controlled Pollination: For self-pollinated crops, cover flowers with a bag and pollinate by hand.



Example: Tomato, chilli, etc.

Significance of Isolation

- ✓ Minimizes genetic contamination.
- ✓ Enhances seed certification standards.
- ✓ Improves market value and farmer confidence.

Conclusion

Maintaining genetic purity through effective isolation techniques is a cornerstone of successful seed production. Proper application of spatial, temporal, and barrier methods, along with vigilant roguing, ensures that farmers receive high-quality seeds with reliable performance.

References

Smith, J. S. C. and J. C. Register III. (1998). Genetic purity and testing technologies for seed quality: a company perspective. *Seed Science Research*, 8(2): 285-294

Sendekie, Y. (2020). Review on; Seed genetic purity for quality seed production. *International Journal of Scientific Engineering and Science*, 4(10): 1-7.

Bhuvana, L., Jha, R. and Keerthana, D. Seed Testing For Genetic Purity. *Seed Science & Technology*, 94.

Farmers' Organizations and Sustainable Development

Karishma Sharma

Abstract

Farmers' organizations play a pivotal role in promoting sustainable development by empowering agricultural communities, particularly smallholder farmers, to collectively address economic, social, and environmental challenges. These organizations enhance access to markets, credit, and agricultural knowledge, while fostering the adoption of sustainable farming practices such as agroecology, crop diversification, and climate-smart agriculture. Through collective action, farmers are better equipped to advocate for supportive policies, improve their livelihoods, and contribute to long-term food security and environmental conservation. Despite their contributions, farmers' organizations face obstacles including limited resources, institutional weaknesses, and political interference. Strengthening these organizations through inclusive policies, capacity-building, and strategic partnerships is essential for achieving sustainable development goals in rural areas. This article examines the multidimensional impact of farmers' organizations on sustainable development and highlights the need for enhanced support to maximize their transformative potential.

Introduction

Farmers' organizations have become instrumental in promoting sustainable development worldwide. These organizations, encompassing cooperatives, unions and grassroots groups, enable farmers especially smallholders to unite, enhancing their collective power to improve livelihoods, advocate for rights and adopt environmentally sustainable agricultural practices. Sustainable development in agriculture involves the integration of economic viability, social equity and environmental health to meet present needs without compromising future generation. This article explores the multifaceted role of farmers' organizations in achieving sustainable development goals.

Role of Farmers' Organizations in Sustainable Development: Farmers' organizations provide crucial platforms for collective action. By organizing, farmers gain access to resources such as credit, technology, markets, and information. They also strengthen their negotiating power, which helps secure fair prices for agricultural produce and inputs, these organizations are vital in supporting sustainable agricultural practices by facilitating knowledge sharing and technology dissemination among members. Sustainable agriculture promoted by farmers' organizations often includes crop diversification, organic farming, and soil and water conservation practices. These approaches enhance productivity and resilience, contributing to food

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security while protecting natural resources. Moreover, farmers' organizations frequently work alongside governments and NGOs to implement policies and programs that support sustainable rural development.

Empowerment of Smallholder Farmers through Collective Action: Smallholder farmers constitute the backbone of global agriculture, yet they face systemic challenges such as limited access to land, financial services and markets Farmers' organizations empower these farmers by pooling resources and knowledge, thus increasing their bargaining power and enabling better participation in policy dialogues. Collective organization also facilitates capacity-building initiatives, including training in sustainable farming techniques and business skills. This empowerment is essential for fostering resilience against climate change and market volatility. For example, the International Fund for Agricultural Development (IFAD, 2019) highlights that farmers' organizations have improved livelihoods by supporting access to credit and promoting environmentally sustainable practices.

Environmental Contributions of Farmers' Organizations: Environmental sustainability is a core focus of many farmers' organizations. By promoting agroecological methods such as integrated pest management, agroforestry and conservation agriculture they contribute to biodiversity conservation, soil fertility, and water resource management. These practices reduce dependency on synthetic chemicals and lower greenhouse gas emissions. Climate-smart agriculture initiatives often involve farmers' organizations in activities like carbon sequestration and climate adaptation strategies. Their role is critical in ensuring that sustainable agricultural practices are locally adapted and socially acceptable, thereby enhancing both environmental health and food security.

Economic and Social Impact: Farmers' organizations also generate significant economic and social benefits. Economically, they help farmers gain access to better markets, improve product quality, and engage in value addition, leading to higher incomes (Bosc *et al.*, 2019). Socially, these organizations promote inclusion by supporting marginalized groups, including women and youth, enhancing social cohesion and reducing rural poverty. Empowering women within these organizations has shown to improve household nutrition and education outcomes, fostering broader community development (World Bank, 2020). Additionally, cooperative business models facilitate reinvestment into sustainable farming and rural infrastructure, driving long-term community resilience.

Challenges Facing Farmers' Organizations: Despite their importance, farmers' organizations encounter numerous challenges. These include limited financial resources, political interference, lack of infrastructure, and sometimes weak institutional capacity (IFAD, 2019). Additionally, globalization and market fluctuations pose risks to their sustainability. To overcome these challenges, it is critical to strengthen policies that support farmers' organizations, invest in capacity building, and promote partnerships among governments, NGOs, and the private sector. Such efforts can enhance the effectiveness of farmers' organizations in driving sustainable development.

Conclusion

Farmers' organizations are key actors in advancing sustainable development. By empowering farmers, promoting environmentally sound agricultural practices, and fostering economic and social inclusion, they contribute significantly to global food security and rural development. Addressing their challenges through supportive policies and partnerships is essential for maximizing their impact and ensuring a sustainable future for agriculture.

References

Altieri, M. A. and Nicholls, C. I. (2020). Agroecology and the transition to sustainable food systems. *Agriculture and Human Values*, 37(3): 623-625.

Bosc, P. M., Vagneron, I. and Loconto, A. (2019). Farmers' organizations and sustainable agriculture: Challenges and opportunities. *Sustainability*, 11(6):, 1681.

FAO. (2017). The future of food and agriculture Trends and challenges. Food and Agriculture Organization of the United Nations. http://www.fao.org/3/i6583e/i6583e.pdf

World Bank. (2020). Agriculture and food: Improving livelihoods for smallholder farmers. World Bank. https://www.worldbank.org/en/topic/agriculture/overview

IFAD. (2019). Rural development report 2019: Creating opportunities for rural youth. International Fund for Agricultural Development. https://www.ifad.org/en/web/knowledge/publication/asset/41109468

Pretty, J., Benton, T., Bharucha, Z. P., Dicks, L., Flora, C., Godfray, H. C. J., ... and Wratten, S. (2018). Global assessment of agricultural system redesign for sustainable intensification. *Nature Sustainability*, 1(8): 441-446.

Nutritional Composition and Health-Promoting Properties of Cassava

Deepali Mudgal and Kirti

Introduction

A staple food in underdeveloped nations, cassava (*Manihot esculenta*) supplies more than half a billion people with a basic diet. The Food and Agriculture Organization (FAO) of the United Nations says so. In developing nations, cassava ranks fourth in terms of food crops, behind wheat, maize, and rice. The largest producer of cassava worldwide is Nigeria. Other names for it include tapioca, yucca, and manioc. Because of their ready-to-eat, simple, and affordable nature, as well as their digestive principles and crucial diet, cassava products hold a significant place in the snack and bread industries. Essential micronutrients like iron, zinc, and vitamins A, B, and C are also found in cassava.

Additionally, cassava includes certain anti-nutrients that, when consumed in excess, might affect human health. However, before usage for nutritional purposes, the anti-nutrients can be detoxified by cooking properly and soaking overnight. To reduce the plant's anti-nutrient and carcinogenic content, bio-fortification is used to boost the protein, mineral, and vitamin contents of cassava (Bayata, 2019).

The Nutritiousness of Cassava: The particular tissue (root or leaf) and a number of other variables, including the plant's age, variety, location, and environmental circumstances, all affect the composition of cassava. The nutritionally significant parts of the mature cassava plant are the roots, which make up 50% of the plant, and the leaves, which make up 6%. Cassava components (Okigbo and B.N, 1980). In Table 1, the proximate compositions of cassava who roots and leaves are reported.

Table 1: Nutritional Composition of Cassava roots and leaves (Bradbury *et al.*, 1974)

Proximate composition	Cassava roots	Cassava leaves
Food Energy (kcal)	100-149	91
Moisture (g)	45.9-85.3	64.8-88.6
Dry weight (g)	29.8-39.3	19-28.3
Protein (g)	0.3-3.5	1.0-10.0
Lipid (g)	0.03-0.5	0.2-2.9
Total carbohydrate (g)	23-35.7	7-18.3
Dietary fiber (g)	0.1-3.7	0.5-10.0
Ash (g)	0.4-1.7	0.7-4.5

While cassava tapioca is low in fats and proteins, it is high in carbohydrates. The nutritional content of cassava tapioca meal was increased by blending it with Jamaican nutmeg (*Monodora myristica*), African oil bean (*Pentaclethra macrophylla*), and coconut palm (*Cocos nucifera*). The protein content of tapioca flavored with coconut palm, African oil bean, and Jamaican nutmeg rose from 0.88% in cassava without additive to 3.94%, 5.69%, and 8.31%, respectively. The lipid content of the cassava tapioca flavored with Jamaican nutmeg,

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coconut palm, and African oil bean improved from 0.5% to 11%, 19%, and 27.50%, respectively. The mineral composition of cassava tapioca meal was also enhanced by these additives, since macro-elements like calcium, potassium, and phosphorus were present in sufficient amounts.

How cassava affects different health issues

Cassava's impact on cardiovascular illness: Iron is the most valuable mineral found in tapioca. It is necessary for the human body to operate normally and helps produce new red blood cells, which helps to prevent anemia and related disorders. Peripheral organ systems and extremities are assured a healthy flow of blood and oxygen to maintain those cells healthy and functioning at their best levels when the body produces more red blood cells (RBCs) (Wobeto *et al*., 2006).

Cassava's Impact on Digestive Tract Issues: Tapioca is a rich source of dietary fiber. Although fiber has been directly associated with aiding several bodily functions, its effects on digestion are the most evident. By giving feces more volume, fiber facilitates its passage through the digestive system, preventing constipation, bloating, intestinal pain, and even more severe diseases like colon cancer. Additionally, by removing extra cholesterol from the walls of arteries and blood vessels, fiber promotes heart health and helps prevent atherosclerosis and its related problems, such as heart attacks and strokes (Jayasri *et al.*, 2011).

Cassava's Impact on Blood Pressure: Additionally, tapioca contains potassium, which has the vasodilatory effect of lowering blood vessel and artery stress and tension. This can lessen the burden on the cardiovascular system and improve blood flow to various body areas. As a result, there will be less atheroscleosis and a significantly lower risk of blood clots becoming lodged and leading to life-threatening conditions like heart attacks or strokes. Additionally, potassium is essential for maintaining the body's fluid balance. When potassium and sodium are in the right proportions, all fluid exchanges can occur smoothly, which increases energy and metabolic efficiency even more (Trinidad *et al*., 2013).

Cassava's Impact on Celiac Disease: Cassava flour is a good alternative to rye, oats, barley, and wheat because it doesn't contain the allergic protein gluten. Eating meals prepared with tapioca or cassava flour can help those with celiac disease and other gluten-based sensitivities (Dorota *et al*., 2014).

Effect of Cassava on Diabetes: Diabetes mellitus is a syndrome caused by a variable interaction of environmental and genetic factors. It is characterized by abnormal insulin secretion (Type 1) or insulin receptor or post-receptor (Resistance, Type 2) events that affect metabolism involving carbohydrates, proteins, and fats and, in certain cases, damage the Â-cells of the pancreas, liver, and kidney. As of right now, there is no satisfactory effective therapy to cure diabetes mellitus. The quest for novel pharmacological classes to treat this illness is necessary because, despite their limited effectiveness, present medicines do have certain negative effects.

In light of this, numerous compounds derived from plants have been discovered to have anti-diabetic properties with no adverse effects, and research is still ongoing (Abo-salem *et al*., 2009). Using natural items to manage hyperglycemia and related disorders is becoming more popular. The therapeutic properties of cassava have been rediscovered. Numerous biological properties of cassava have been documented, including the anti-oxidant, oxygen radical. The primary cause of cassava's (and its extracts') scavenging action is the presence of flavonoids and phenolic compounds. Numerous research conducted on experimental animals have proven the positive effects of cassava on diabetes (Ani *et al*., 2012).

Neurological and Bone Health: Iron, calcium, and vitamin K are abundant in tapioca and are all crucial for bone growth and protection. As we age, our bone mineral density declines, leading to diseases like osteoporosis and osteoarthritis as well as overall weakness and stiffness. Regular consumption of tapioca can help to preserve, develop, and protect our bones as we age. Having an abundance of vitamin K is beneficial for our mental health in addition to promoting osteotrophic activity. By promoting neuronal activity in the brain, vitamin K has been demonstrated to lower the risk of Alzheimer's disease. According to Charles *et al*. (2004), vitamin K prevents free radicals from breaking down brain tissues by keeping neuronal pathways engaged and active.

Factors that hinder nutrition: Large-scale cassava substitution requires the development of technology that lowers the high moisture and HCN content of cassava tubers. According to Ngiki et al. (2014), the cyanide content of cassava varies from 75 to 1,000 mg/kg, depending on the plant's age and type, soil conditions, fertilizer presence, and weather. Lotaustralin or ethyl linamarin (7%), as well as linamarin (93%) are the two forms of cyanogenic glucosides found in cassava. They are not detrimental to the plant and provide as supplies of aspartic acid, glutamic acid, and glutamine. Although linamarin is coupled to cyanide ions, it shares molecular similarities with glucose. Depending on the type, fresh tuber can contain anywhere between 2 and 395 mg/100 g of linamarin (Yeoh and Yruong, 1993). The linamarase enzymes found in cassava roots convert linamarin and lotaustralin to HCN when the roots are crushed or sliced (Cardoso *et al*., 2005; Santana *et al*., 2002). According to Ngiki *et al.* (2014), the amount of cyanogenic glucosides in leaves is six times greater than that in roots, and it decreases as the leaf ages.

References

Ani, A. I., Atangwho, I. J., Agiang, M. A. and Alozie, Y. E. (2012). Biochemical effects of some traditional Nigerian diets in experimental diabetic rat models. *International Journal of Biochemistry Research*, 2(2): 70-77.

Charles, Y. H Chang, W. C Ko, Sriroth K and Huang, T. C. (2004). Some physical and chemical properties of starch isolates of cassava genotypes. *Starch/starke*, 56: 413- 418.

Bayata, A. (2019). Review on Nutritional Value of Cassava for Use as a Staple Food. *Science Journal of Analytical Chemistry*, 83-91.

Bradbury, J. H. and Holloway, W. D (1988). Cassava, *M. esculenta*. Chemistry of tropical root crops: significance for nutrition and agriculture in the pacific. Australian centre for international agricultural research, Monograph 6, Canberra, Australia, 76-104.

Dorota, L., Z. Rafa, G. Halina and Marek, S. (2014). Gluten Free Bread in a Diet of Celiacs. *International Journal of Celiac Disease*, 2(1): 11-16.

Jayasri, P., Narendra, D, Naik and Elumalai, A. (2011). Evaluation of anthelmintic activity of Manihot Esculenta leaves. *International Journal of Current Pharmacy Research*, 3: 115-116

Morgan, Choc. (2016). Cassava: Nutrient composition and nutritive value in poultry diets. *Animals Nutrition*, 2: 253 -261

Ngiki, Y. U., Igwebuike, J U., Moruppa, S. M. (2014). Utilisation of cassava products for poultry feeding: a review. *International Journal of Science and Technology*, 2(6): 48e59.

Okigbo, B. N. (1980). Nutritional implications of projects giving high priority to the production of and staples of low nutritive quality. In the case for cassava (*Manihot esculenta*, Crantz) in the humid tropics of West Africa. *Food Nutrient Bulletin*, 2: 1-10.

Okwu Donates E., (2015). Improving the nutritive value of cassava tapioca meal with local spices. *Journal of Nutraceuticals, Functional & Medical Foods*, 3: 43-50.

Understanding Heteroscedasticity: Causes, Consequences, Detection and Remedies

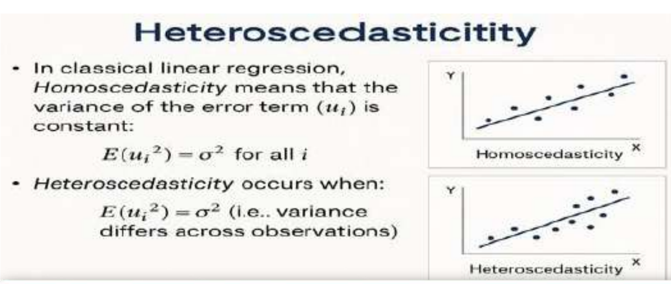
Vishnu Priya B. and Kavichelvan V.

Abstract

Heteroscedasticity refers to the condition in regression analysis where the variance of the error term is not constant across observations, violating the classical linear regression assumption of homoscedasticity. While Ordinary Least Squares (OLS) estimators remain unbiased and consistent under heteroscedasticity, they lose efficiency and are no longer the Best Linear Unbiased Estimators (BLUE). This leads to biased standard errors, unreliable t-tests and F-tests, and incorrect confidence intervals, resulting in misleading inferences. Detection methods include graphical techniques such as residual plots and formal statistical tests like the Breusch-Pagan, White, Glejser, Park, and Goldfeld-Quandt tests. Remedies include Weighted Least Squares (WLS), Generalized Least Squares (GLS), model transformation (e.g., logarithmic or square-root), and robust standard errors to ensure valid inference. Addressing heteroscedasticity is crucial for improving the accuracy, efficiency, and reliability of econometric models.

Heteroscedasticity?

In classical linear regression, Homoscedasticity means that the variance of the error term (u_i) is constant. This implies that no matter the value of the independent variable(s), the spread (variability) of the error term remains the same. This condition allows Ordinary Least Squares (OLS) estimators to be efficient (i.e., have minimum variance), and valid statistical inference (t-tests, F-tests) can be made.



One of the important assumptions of the classical linear regression model is that the variance of each disturbance term ui, conditional on the chosen values of the explanatory variables, is some constant number equal to σ2. This is the assumption of homoscedasticity, or equal (homo) spread (scedasticity), that is, equal variance. Symbolically,

$$Eu_i^2 = \sigma^2 \qquad i = 1, 2, \ldots, n$$

Notice the subscript of σ2, which reminds us that the conditional variances of ui (= conditional variances of Yi) are no longer constant.

- ✓ One of the assumptions of the classical linear regression (CLRM) is that the variance of u_i, the error term, is constant, or homoscedastic.

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- Reasons are many, including:
  - Following the error models
  - As income grow, people have more discretionary income
  - As data collection techniques improve, variance is likely to decrease

Consequences of Heteroscedasticity

In classical linear regression, homoscedasticity (constant variance of the error term) is one of the key assumptions that ensures the reliability of the OLS (Ordinary Least Squares) estimators. When heteroscedasticity occurs (i.e., when the variance of the error term differs across observations), it violates this assumption and leads to several important consequences:

OLS Estimators Remain Unbiased and Consistent

- Even in the presence of heteroscedasticity, the point estimates of the coefficients.
- The estimators are also consistent, meaning that as the sample size grows, the estimates converge to the true values.

What stays valid: The mean of the estimated coefficients is still correct in repeated samples.

Inefficiency: OLS is No Longer BLUE

The Gauss-Markov Theorem states that under classical assumptions, OLS is BLUE:

Best: Minimum variance among all linear unbiased estimators.

Linear: A linear function of the dependent variable.

Unbiased: On average, hits the true value.

However, with heteroscedasticity:

- OLS is no longer the "Best" estimator, because it does not minimize variance anymore.
- This means you could find other estimators (like WLS) that are more efficient.

Biased Standard Errors

While coefficient estimates remain correct, their standard errors become unreliable:

Some may be underestimated, others overestimated.

This affects:

- t-tests (used to test the significance of individual coefficients).
- F-tests (used to test joint significance of variables).

Impact: You might falsely conclude that a variable is statistically significant when it is not (Type I error), or vice versa (Type II error).

Incorrect Confidence Intervals

Since standard errors are biased, confidence intervals calculated using them will also be misleading:

- Too narrow (giving false precision), or
- Too wide (masking real effects)

This affects the reliability of predictions and inference in your regression model.

Alternative Estimators: WLS and GLS

WLS (Weighted Least Squares)

- A method that assigns weights to each observation to correct for unequal variances.
- Ideal when the form of heteroscedasticity is known or can be reasonably assumed.

GLS (Generalized Least Squares)

- An extension of WLS.

- ✓ More flexible; it transforms the model to eliminate heteroscedasticity and then applies OLS to the transformed model.
- ✓ It provides BLUE estimators even in the presence of heteroscedasticity.

Detection Methods for Heteroscedasticity

Detecting heteroscedasticity is crucial to ensure valid statistical inference in regression analysis. Here are the main methods categorized into graphical and formal tests:

Graphical Methods

These are informal but useful ways to visually inspect the residuals for unequal variance.

Plot of Squared Residuals vs. Predicted Values (Ŷ)

- ✓ Plot the squared residuals on the Y-axis against the predicted values on the X-axis.
- ✓ In the presence of heteroscedasticity:
  - The spread increases or decreases with Y^i
  - A fan or cone shape appears in the plot.

Histogram of Residuals

- ✓ Visualize the distribution of residuals.
- ✓ In homoscedasticity: residuals are randomly scattered and roughly normally distributed.
- ✓ In heteroscedasticity: you may observe asymmetry or clusters in certain regions.

These methods are subjective and should ideally be followed by formal statistical tests.

Formal Statistical Tests

These are objective hypothesis tests used to detect the presence of heteroscedasticity.

Breusch-Pagan (BP) Test

Step 1: Run the original OLS regression and obtain residuals u^i\hat{u}_i.

Step 2: Calculate u^i2 (squared residuals).

Step 3: Regress u^i2 on the independent variables used in the original model.

White's Test

- ✓ More general and robust than the BP test.
- ✓ Detects both linear and non-linear forms of heteroscedasticity.

Steps

- ✓ Run the original regression and compute u^i2\hat{u}_i^2.
- ✓ Regress u^i2\hat{u}_i^2 on:
  - All independent variables,
  - Their squared terms, and
  - All pairwise cross-products.

Other Tests

These provide additional or alternative methods for detecting specific types of hetero-scedasticity.

Park Test: Assumes a log-linear relationship between the variance of the error term and one explanatory variable.

Glejser Test: Regress the absolute value of residuals |u^i| on an independent variable or variables.

Goldfeld-Quandt Test

- ✓ Used when heteroscedasticity is suspected in relation to a specific variable.
- ✓ Split data into two groups based on the suspected variable (excluding the middle portion).
- ✓ Run separate OLS regressions and compare the residual variances:

- Use the F-distribution to test significance.

Spearman's Rank Correlation Test

- ✓ Non-parametric test to check if residuals are correlated with a variable suspected to cause heteroscedasticity.
- ✓ Rank the variable and residuals and compute Spearman's correlation.
- ✓ A high correlation implies heteroscedasticity.

Remedial Measures for Heteroscedasticity

Once heteroscedasticity is detected in a regression model, it needs to be addressed because it violates the OLS assumption of constant variance, leading to inefficient estimates and unreliable inference. Below are four effective methods to deal with heteroscedasticity:

Method	Key Idea	When to Use
WLS	Reweights observations to stabilize variance	When variance structure is known or estimable
Model Transformation	Stabilizes variance using log/sqrt transformations	When variance increases with Y or X
Robust SEs	Adjusts standard errors for inference	When form of heteroscedasticity is unknown
Model Respecification	Fixes specification errors causing heteroscedasticity	When model may be missing variables or mis-specified

References

Breusch, T. S. and Pagan, A. R. (1979). A simple test for heteroscedasticity and random coefficient variation. *Econometrica*, 47(5): 1287-1294.

Gujarati, D. N. and Porter, D. C. (2009). *Basic econometrics* (5th ed.). McGraw-Hill Education.

Greene, W. H. (2012). *Econometric analysis* (7th ed.). Pearson Education.

Stock, J. H. and Watson, M. W. (2015). *Introduction to Econometrics* (3rd ed.). Pearson.

White, H. (1980). A heteroskedasticity-consistent covariance matrix estimator and a direct test for heteroskedasticity. *Econometrica*, 48(4): 817-838.

Wooldridge, J. M. (2013). *Introductory Econometrics: A modern approach* (5th ed.). South-Western, Cengage Learning.

Nanotechnology in Seed Science

G. Mahalakshmi, S. Subhashini and K. Chozhan

Abstract

Nanotechnology, the manipulation of materials at the nanoscale (1-100 nm), has emerged as a revolutionary approach in agriculture and seed science. In seed technology, nanoparticles are being explored for their potential to improve seed germination, enhance nutrient uptake, provide controlled delivery of agrochemicals, and protect seeds against biotic and abiotic stresses. Their unique physicochemical properties allow precise interactions with seed tissues, thereby promoting vigor, uniformity, and resilience. This article highlights the applications of nanotechnology in seed priming, seed coating, disease resistance, and genetic improvement. It also discusses the benefits, challenges, and prospects of integrating nanotechnology into modern seed science.

Introduction

Seed science forms the foundation of sustainable agriculture, ensuring crop productivity and food security. With growing challenges such as climate change, pest infestations, and declining soil fertility, innovative technologies are required to support seed quality and performance. Nanotechnology, with its ability to deliver targeted solutions at the molecular level, offers promising applications for seed improvement.

Applications of Nanotechnology in Seed Science

Seed Priming with Nanoparticles

- ✓ Nanoparticles such as zinc oxide (ZnO), titanium dioxide (TiO_2), and silver nanoparticles are used in seed priming.
- ✓ They enhance germination speed, improve seedling vigor, and activate stress-responsive enzymes.
- ✓ Nano-priming improves water uptake efficiency and reduces germination time.

Seed Coating and Delivery Systems

- ✓ Nanoparticles can be used in seed coatings to deliver micronutrients, pesticides, or growth regulators.
- ✓ Controlled and sustained release reduces input wastage.
- ✓ Coatings can also enhance seed shelf life and protect against storage pests.

Disease and Pest Resistance

- ✓ Nano-based fungicides and bactericides protect seeds against soil-borne pathogens.
- ✓ Silver nanoparticles have antimicrobial effects,

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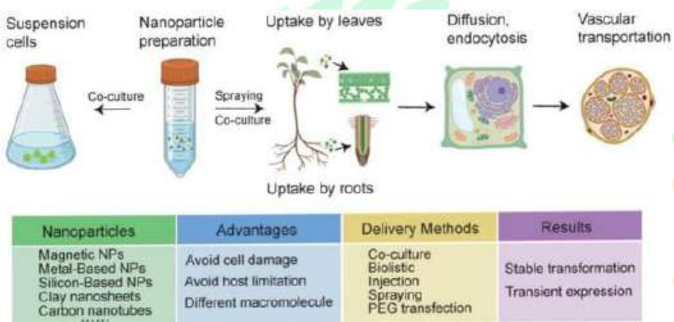
reducing fungal infections during germination.

Abiotic Stress Tolerance

- ✓ Nanoparticles improve seed tolerance against drought, salinity, and temperature extremes.
- ✓ They enhance antioxidant activity and reduce oxidative damage in stressed seedlings.

Genetic and Molecular Applications

- ✓ Nanocarriers aid in gene transfer for developing improved seed varieties.
- ✓ They provide a non-invasive method for DNA/ RNA delivery to plant cells.



Benefits of Nanotechnology in Seed Science

- ✓ Faster and uniform germination.
- ✓ Enhanced nutrient uptake and seedling growth.
- ✓ Reduced dependency on chemical fertilizers and pesticides.
- ✓ Environmentally friendly delivery of agrochemicals.
- ✓ Scope for precision agriculture through smart seeds.

Limitations and Challenges

- ✓ Potential toxicity of nanoparticles to seeds, soil, and ecosystems.
- ✓ High cost of large-scale production and application.
- ✓ Lack of regulatory guidelines and biosafety assessments.
- ✓ Limited awareness and adoption among farmers.

Future Prospects

Nanotechnology holds immense potential for transforming seed science by integrating smart delivery systems, stress-tolerant varieties, and environmentally sustainable seed technologies. With further research and safety regulations, nano-enabled seed systems could become a key driver of global food security.

Conclusion

Nanotechnology offers innovative solutions to enhance seed quality, protect against stresses, and improve agricultural productivity. While challenges of safety and cost remain, its integration into seed science marks a step toward sustainable and resilient farming systems.

References

Gogos, A., Knauer, K. and Bucheli, T. D. (2012). Nanomaterials in plant protection and fertilization: Current state, foreseen applications, and research priorities. *Journal of Agricultural and Food Chemistry*, 60(39): 9781-9792.

Wang, P., Lombi, E., Zhao, F. J. and Kopittke, P. M. (2016). Nanotechnology: A new opportunity in plant sciences. *Trends in Plant Science*, 21(8): 699-712.

Prasad, T. N. V. K. V. and Choudhary, R. C. (2019). Nanotechnology applications in seed science. *Seed Science and Technology*, 47(1): 1-10.

Why We Need Digital Trust: The Story of Blockchain in Agriculture

Phani Rama Krishna, J. Sunil, M. Sampath Kumar, R. Sathish and P. Rajshekar Reddy

Introduction

The way our food travels from the farm to our plate is often unclear and unreliable. For decades, agriculture has depended on old methods such as paper records or single company databases to track the movement of food. These traditional systems have several problems. Records can be easily changed, lost, or manipulated. It is also very difficult to check if the information is true. When a food safety issue occurs, it can take several days or even weeks to find where the problem started. This delay causes a loss of time, money, and consumer trust. However, today's agricultural systems face several challenges such as lack of transparency, unfair pricing, fake inputs, and difficulty in tracing food products from the farm to the consumer. To solve these issues, modern technologies like Blockchain are being introduced to make farming smarter, safer, and more reliable. Blockchain technology was developed to create digital trust and solve problems of unreliable record-keeping. It stores all data in a shared and secure system that cannot be easily altered. Because the information is distributed across many computers rather than kept in one place, it becomes transparent and highly secure. Everyone involved from farmers to consumers can access the same verified data, making it possible to trace food products instantly from the farm to the plate.

What is Blockchain Technology?

Blockchain is a decentralized digital ledger system that uses cryptography to secure and verify transactions. Being decentralized means that it is not controlled by any single person or company. Instead, it operates through a network of computers, each keeping a copy of the same information. The technology first gained attention through Bitcoin, created by Satoshi Nakamoto, but its applications now extend far beyond cryptocurrencies. In agriculture, blockchain plays an important role in

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improving traceability, transparency, and trust within the food supply chain. Each transaction is stored in a block, which is linked to the previous one, forming a continuous and unbroken chain. This structure makes it extremely difficult to alter or delete any record. Because all participants in the network can view and verify the same data, blockchain ensures greater transparency, builds trust, and makes it easier to track information or assets at every stage of the process.

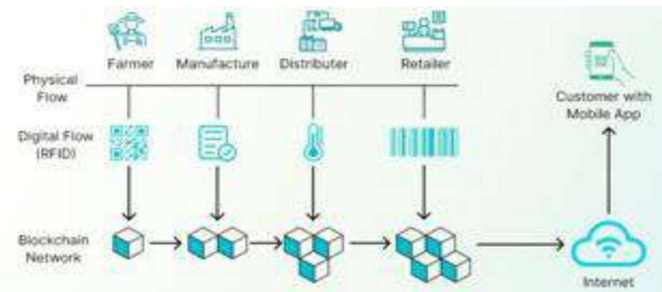


Figure: Process of block chain technology in agriculture product supply chain

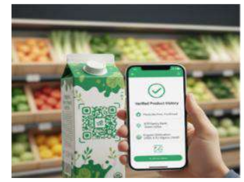
Blockchain Technologies Be Used in Agriculture?

Blockchain is not just a digital tool, it is a fundamental shift in how trust is established. It is very useful in agriculture because it helps make the entire farming and food system more transparent, secure, and trustworthy. Here are some simple ways it can be used:

Tracking Farm Products (Traceability): Blockchain can record every step of a crop's journey from planting, harvesting, and processing to packaging and selling. This helps farmers and consumers know exactly where the food came from and ensures its quality and safety.

Fair and Transparent Payments: Farmers can get direct payments through blockchain without middlemen. Smart contracts (automatic digital agreements) can ensure that farmers are paid on time once they deliver their products.

Seed and Input Quality Monitoring: Blockchain can store details about seed quality, fertilizers and pesticides used in farming. This makes it easy to check whether the inputs are genuine and safe for crops. It also creates a permanent record verifying quality standards, organic certifications, and compliance with ethical sourcing norms.



Weather and Soil Data Sharing: Data from IoT sensors (like soil moisture or temperature sensors) can be stored securely on blockchain. This helps in better farm management and planning.

Supply Chain Management: Every step of the supply chain from farmer to wholesaler to retailer can be recorded on blockchain. This prevents fraud, food spoilage, and record manipulation, making the process faster and more reliable.

Access to Credit and Insurance: Because blockchain keeps accurate farm records, it helps farmers prove their credibility to banks or insurance companies, making it easier to get loans or crop insurance.

Benefits of Blockchain in Agriculture

- ✓ Builds trust among farmers, traders, and consumers.
- ✓ Increases transparency and reduces fraud.
- ✓ Improves food safety through accurate tracking.

- ✓ Reduces paperwork and saves time.
- ✓ Encourages fair trade and quick payments.

Challenges in Adopting Blockchain

Despite its benefits, blockchain still faces some problems in agriculture:

- ✓ Lack of awareness among farmers.
- ✓ Poor internet connectivity in rural areas.
- ✓ High setup cost and need for technical know-ledge.
- ✓ No clear government policies for blockchain use in farming.
- ✓ Data privacy and security concerns farmers may worry about who owns or can see their farm data.
- ✓ Smallholders who may not see immediate benefits from blockchain.

The future of agriculture is not just about growing more; it's about growing smarter, together, with unbreakable trust.

Prospect of Mulberry Sericulture in West Sikkim

Thangjam Ranjita Devi

Sericulture, the cultivation of silkworms for silk production, is an important agro-based industry. The mulberry silkworm *B. mori* holds significant cultural, economic and scientific value (Kankana-wadi *et al*., 2025). The contribution of the domestic silkworm, as an insect of great value to the human economy, has long transcended the single economic category (Zihan Yu., 2025). The domestic silkworm *B. mori*, can also be exploited to improve the economic status of farmers in West Sikkim.

The sericulture sector of neighbouring state of West Bengal, consumes Multi x Bi (Nistari x SK6xSK7) cross breed and Multi x Multi hybrid (Nistari x M12W), owing to its high temperature and humidity. Multivoltine × Bivoltine and Multi x Multi hybrids often fall short of international quality standards due to the inferior silk quality. Therefore, shift toward bivoltine sericulture is crucial for producing raw silk that meets global benchmarks (Datta and Pershad, 2002). Often there is lack of bivoltine seed which is a substantial issue impacting the sericulture belts of West Bengal. The state does not produce enough bivoltine seeds locally. Most of the bivoltine seed is obtained from other southern part of India of Karnataka and Tamil Nadu, which surges costs and more mechanical damage during transport. One of the crucial factors for insufficient production of bivoltine seed is the hot and humid climatic condition of West Bengal. Sikkim the neighbouring state of West Bengal experiences a mainly congenial climate due to its high altitude and mountainous terrain from March to September. Eri, Muga and mulberry silkworm constitute the sericulture sector of Sikkim. West District of Sikkim, is a promising sericulture belt especially for Mulberry sericulture. Approximately 181 farmers practised mulberry sericulture in west Sikkim. Silkworm rearing is practised three times in a year during the congenial climatic condition. SK6 x SK7, the bivoltine hybrid is reared in the farmers' field. BC259 mulberry variety which is compatible for hilly regions like Kalimpong and parts of North-east India, is used as silkworm fed. West Sikkim can exploit its congenial climatic condition for increased production of SK6 x SK7 cocoons. Mass production of SK6 x SK7 silkworm seed can be undertaken for sale of scientifically certified silkworm seed to West Bengal and other North East states.

The bivoltine breeds and hybrids could spin better quality cocoons and produces silk than crossbreeds (Hazarika *et al.*, 2023). Owing to the better silk quality of Bivoltine hybrids, and West Sikkim being a bivoltine zone, silkworm reelers can be trained and developed so that the production of raw silk can be improved and hence enhance income for the sericulture farmers.

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Fig. 1: Cultivation of Mulberry sapling at the roadside of Tikpur, West Sikkim

Fig. 2: Chawki rearing of SK6 x SK7 at West Sikkim

One of the lacunae, of mulberry plantation is small and fragmented land holdings of the sericultural farmers. The Directorate of Sericulture, Sikkim has taken up initiative like road side mulberry cultivation at the proximity of the sericultural farmers which can enhanced the Mulberry cultivation area. West Sikkim being known for its scenic beauty and tourist attraction, tourism can be clumped with Sericulture where tourist can explore the silkworm cultivation which can enhance the income of the farmers. West Sikkim, thus have a good prospect of mulberry sericulture thereby enhancing the income of the farmers.

References

Datta, R. K. and Pershad, G. D. (2002). Combining ability among multivoltine × bivoltine silkworm, *Bombyx mori* L. *Sericologia*, 28: 21-28.

Hazarika, D. J., Patil, K. M. G., Gowda, M. L., Jagadeesh, K. and Manjunatha, H. B. (2023). New Bivoltine Hybrids of the Silkworm (*Bombyx mori* L.) Performance at Farmer's Site. *International Journal of Environment and Climate Change International*, 13 (11): 4695-4701.

Kankanawadi, N., Gowda, M., Aramani, K., Veenita, M. K., Shwetha, G. V. and Gagana Sindhu, S. (2025). Reeling and Raw Silk Assessment of New Bivoltine Silkworm Double Hybrids Tolerant to High Temperature and Muscardine Disease. *Journal of Advances in Biology & Biotechnology*, 28(8): 114-22.

Zihan, Yu. (2025). Progress in Genetic Engineering Research of Silkworms. *International Journal of Biology and Life Sciences*, 10(1): 103-112.

Scientific Approaches for the Preservation of Custard Apple (*Annona squamosa*) Pulp

Gurve V. R. and Patil S. J.

Abstract

Custard apple (*Annona squamosa*), a climacteric fruit valued for its unique flavor and creamy texture, presents several post-harvest challenges, particularly in pulp processing and storage. The high enzymatic activity in the pulp, especially peroxidase and polyphenol oxidase, leads to rapid discoloration and development of bitterness upon exposure to air and heat. Conventional thermal preservation methods are unsuitable due to the formation of undesirable flavors. This article reviews the current scientific strategies for custard apple pulp preservation, with a focus on chemical preservation, enzymatic control, and cold chain management based on published research and experimental findings.

Introduction

Custard apple is widely consumed in tropical and subtropical regions, either as fresh fruit or processed pulp. However, commercial utilization is limited due to its short shelf life and susceptibility to enzymatic browning and flavor deterioration during processing and storage. Exposure of pulp to atmospheric oxygen initiates peroxidase activity, turning the pulp pink, while thermal treatment above 55°C induces bitterness and off-flavors, rendering conventional heat-based preservation methods inapplicable (Bhatia *et al.*, 1961). Therefore, the development of non-thermal and chemical preservation protocols is critical for enhancing the commercial viability of custard apple pulp.

Challenges in Custard Apple Pulp Processing

Key issues associated with custard apple pulp processing include:

Enzymatic Browning: Due to polyphenol oxidase (PPO) and peroxidase activity.

Bitterness Development: Heating above 55°C leads to breakdown of sensitive compounds into bitter-tasting substances.

Microbial Spoilage: High sugar and moisture content favors microbial growth.

Color and Flavor Loss: Especially during prolonged storage or improper packaging.

Attempts to apply standard thermal preservation techniques (such as pasteurization) often result in irreversible quality degradation, making the need for optimized, non-thermal preservation essential.

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Chemical Preservation Strategies

Use of Citric Acid and Sodium Benzoate: Bhatia *et al.* (1961) demonstrated that a combination of 1% citric acid and 0.1% sodium benzoate, along with 50-100 ppm of sulphur dioxide (SO_2), effectively reduced enzymatic browning and maintained the sensory quality of the pulp during storage.

Potassium Metabisulphite (KMS): Potassium metabisulphite has proven to be a highly effective preservative for custard apple pulp. Various studies reported:

- ✓ KMS 1500 ppm preserved the pulp for up to six months without significant deterioration (Sravanthi *et al.*, 2014).
- ✓ KMS 1.5% combined with -18°C storage maintained color, flavor, and microbial quality (KrishiKosh, 2023).
- ✓ A combination of ascorbic acid (1200 ppm) with KMS (200 ppm) resulted in superior physico-chemical stability over 180 days of storage (Barge *et al.*, 2023).
- ✓ Fatima and Sindhu (2019) reported that sodium benzoate + KMS at 2000 ppm inhibited microbial activity effectively over a 40-day storage period.

Non-Thermal and Cold Chain Protocols

Given the pulp's sensitivity to heat, cold storage and rapid freezing techniques are preferred.

Blast Freezing and Deep Freezing: Bakane *et al.*, 2015 recommended the following protocol:

- ✓ Dissolve 1 g KMS per kg of pulp in 5 mL of distilled water and mix thoroughly.
- ✓ Blast freeze at -40°C for 24 hours, followed by storage at -20°C in HDPE packaging to inhibit enzymatic browning and microbial growth.

Modified Pasteurization with Immediate Cooling: Jaishankar *et al.*, 2018 (In Techpedia - Gandhian Young Technological Innovation (GYTI) Awards report) suggest the following protocol:

- ✓ Addition of 750-1000 ppm KMS to freshly extracted pulp.
- ✓ Packaging in aluminium foil pouches.
- ✓ Pasteurization at 90°C for 25 minutes, followed by rapid cooling.
- ✓ Storage at -20 ± 5°C, ensuring shelf life beyond 9 months.

However, such thermal methods require fine-tuning to avoid flavor degradation and are only feasible under controlled conditions.

Fig. 1: Flow chart for the preservation of custard apple pulp (Jaishankar *et al.*, 2018)

Role of High Sugar Concentration: Increasing sugar concentration to 40° Brix has been reported to retard enzymatic activity, thereby improving the stability of custard apple pulp. This is likely due to the reduction in water activity, which limits enzyme mobility and microbial growth.

Conclusion

Preservation of custard apple pulp requires a combination of chemical preservation, rapid freezing, and appropriate packaging to ensure retention of its sensory and nutritional quality. Among the most effective treatments are:

Chemical Preservatives: KMS (750-2000 ppm), citric acid (1%), sodium benzoate (0.1%).

Storage Conditions: Immediate blast freezing at -40°C, followed by storage at -18 to -20°C.

Packaging: HDPE or aluminum pouches to prevent oxidation.

Supplementary Techniques: Use of antioxidants (ascorbic acid) and control of Brix level.

Further research is needed to optimize these protocols for industrial-scale applications, including alternative natural preservatives and advanced packaging technologies.

References

Bakane, P. H., Khakare, M. M., Gajabe, M. H., Borkarand, P. A and Khobragade, H. M. (2015). Comparative Storage Study of Custard Apple Separated By Machine and Manual. *International Journal of Agriculture Sciences*, 7(8): 647-651.

KrishiKosh Repository (2023). https://krishikosh.egranth.ac.in/items/7d89d14e-31cd-47e8-b41a-fbf14b99fe99.

Sravanthi, T., Waghrey, K. and Daddam, J. R. (2014). Studies on Preservation and Processing of Custard Apple (*Annona squamosa* L.) Pulp. *IJPAES*, 4(3).

Barge, K. R., Kad, V. P., Wakchaure, G. C. and Yenge, G. B. (2023). Development of Protocol for Preservation of Custard Apple Pulp. *Journal of Agricultural Research and Technology*, 48(2): 223-229.

Bhatia, B. S., Sastry, L. V. L., Krishnamurthy, G. V., Nair, K. G. and Lal, G. (1961). Preservation of Custard Apple (*Annona squamosa*) Pulp. *Journal of Sci. Food Agriculture*, 12.

Jaishankar, H. P., Manjula, K., Kirankumar, G., Sandhayarani, N., Praveen, J. and Laxman, K. (2018). Process for Preservation of Custard Apple Pulp. Techpedia https://gyti.techpedia.in/project-detail/process-for-preservation-of-custard-apple-pulp/11137

Namous, F. and Sindhu, A. (2019). A Study to Combat Microbial Food Spoilage Activities in Custard Apple (*Annona reticulata*) Using a Combination of Chemical Preservatives. *IJISET*, 7(1).

Seed Treatment

Akshitha S., Subhashini and Cholan

Abstract

Seed treatment is a crucial pre-sowing intervention aimed at enhancing seed quality, protecting against pathogens, and improving crop establishment. It involves the application of physical, chemical, and biological agents directly onto seeds to safeguard them from seed-borne and soil-borne diseases, insect pests, and abiotic stress factors. Modern seed treatment practices not only enhance germination, seedling vigor, and uniform crop stand but also reduce the dependency on field-level pesticide applications, thereby lowering input costs and minimizing environmental hazards. The growing emphasis on sustainable agriculture has accelerated the adoption of eco-friendly biological seed treatments using biofertilizers, biocontrol agents, and microbial inoculants. Furthermore, advancements in seed coating, pelleting, and polymer-based formulations have increased precision, effectiveness, and shelf life of treated seeds. By integrating conventional and innovative approaches, seed treatment contributes significantly to yield improvement, resource use efficiency, and environmental sustainability, making it a cornerstone of modern crop production systems.

Introduction

Seed is the most vital input for sustained agricultural productivity, with nearly 90% of food crops raised from seed. In India, where agriculture underpins food security and GDP, quality seed plays a crucial role. However, seed- and soil-borne pathogens and early insect pests often cause heavy losses. Traditional practices like crop rotation and sanitation have declined, while chemical control faces limitations due to cost, resistance, pollution, and health risks. Seed treatment has therefore become an essential strategy to ensure healthy crop establishment, vigor, and uniform growth. It involves applying physical, chemical, or biological agents to seeds before sowing, offering early protection from pests and diseases. Advanced technologies such as coating, pelleting, and polymer formulations have enhanced precision and effectiveness, while biological treatments using biofertilizers and biocontrol agents provide sustainable alternatives to chemicals. By reducing inoculum potential, pesticide use, and production costs, seed treatment safeguards the environment, supports integrated pest management, and enhances yield.

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Thus, it is recognized as a cornerstone of modern, sustainable agriculture.

Methods of Seed Treatment

Physical Seed Treatment-An Alternative to Chemicals

Hot water treatment: An eco-friendly method to control seed-borne diseases by exposing seeds to specific temperatures that kill pathogens without harming the seed. It is effective against diseases like black rot in crucifers and blackleg. Seeds are pre-warmed, immersed in hot water for a fixed time, then cooled and dried. Fungicides like thiram may be applied after treatment, and seeds should be sown soon, not stored. This method works well in crops like tomato, pepper, carrot, cabbage, radish, and spinach, but may damage sensitive seeds such as peas, beans, corn, and some hybrids. Despite limitations, it remains a reliable seed sanitation tool.

Dry Heat Treatment: DHT is a chemical-free method to control seed-borne pathogens and insects. Traditional solarization (sun exposure) is simple but less precise and unsuitable for large-scale use. Modern DHT uses dry hot air, effective for insect control in stored grains and for high-value vegetable seeds (Japan, Korea) to manage viruses and pathogens.Treatments like 65 °C for 4-7 days or 70 °C for up to 4 days can control diseases such as anthracnose in lupine. However, excessive heat may reduce seed viability. Overall, DHT is a precise, eco-friendly, and reliable method for seed sanitation.

Aerated heat treatment: Developed in the late 19th century as an alternative to hot water treatment, which was costly, less precise, and sometimes reduced germination.In this method, seeds are exposed to controlled hot air with specific temperature and humidity, then cooled to avoid damage. Modern systems ensure precise control, making it suitable for large-scale use. It is effective against pathogens in crops like lupin, wheat, barley, oat, lobelia, and sugarcane, controlling diseases such as anthracnose and Alternaria. Aerated steam is a reliable, chemical-free method for seed sanitation and healthy crop establishment.

Radiation treatment: Chemical treatments can leave harmful residues, so radiation methods are explored as eco-friendly alternatives. Techniques include gamma rays, UV light, microwaves, ultrasonic waves, lasers, and ozone.Low doses of gamma irradiation reduce pathogens without harming seeds, sometimes improving germination. UV and laser can control fungi but face challenges in uniform exposure. Ozone treatment is a promising, residue-free method that can boost yields by 10-15%. Overall, radiation treatments provide a chemical-free way to improve seed health and performance, though proper dosage is crucial to protect viability

Chemical and biological seed treatment:

Chemical Seed Treatment: Widely used for rapid control of seed- and soil-borne diseases and insect pests. Fungicides and insecticides are applied directly, sometimes in combination. Modern machines ensure precise large-scale application. However, they do not improve root growth, stress tolerance, or yield.

Biological Seed Treatment: Seeds are coated with beneficial microbes like *Trichoderma*, *Bacillus*, *Pseudomonas*, and *Rhizobi*a. These improve vigor, germination, and stress tolerance. Techniques like biopriming enhance the stability and effectiveness of microbes, offering a sustainable and eco-friendly alternative.

Seed Treatment Using Emersion Techniques

Seed Immersion Methods: Seeds are steeped in aqueous or solvent solutions (with or without chemicals) at different temperatures to eradicate seed-borne organisms.

Seed Soak in Aqueous Fungicides: Ancient method where seeds are soaked in fungicide suspensions or powders to improve germination and control pathogens. Hydration during soaking helps chemicals penetrate more effectively.

Use of Antibiotics: Seeds infected with bacteria are soaked in antibiotic solutions or hot water with/ without chemicals, as surface application alone is not effective.

Seed Soak in Inorganic Chemicals: Seeds soaked in water, mineral solutions ($CaCl_2$, $ZnSO_4$, $CuSO_4$, etc.), or growth regulators (GA, kinetin, ascorbic acid, etc.) improve germination, vigor, stress resistance, and yield.

Seed Dressing: Most common method where seeds are treated with pesticides as dry powders or slurry. Can be done on-farm (mixing in pots, sheets, drums) or industrially using machines for uniform coating.

Seed Coating: Seeds are coated with a binder and chemicals to ensure adherence. Modern machines apply slurry formulations for large volumes. Adhesives like gum arabic or oils improve sticking.

Seed Pelleting: Changes seed shape and size by adding binders and fillers, improving handling and precision planting. Useful for small or irregular seeds, reduces phytotoxicity, but is more expensive

Fluid Drilling: Partially germinated seeds are mixed in a gel and sown directly. Maintains moisture but needs special equipment and adds cost.

Seed Priming: Partial hydration of seeds to trigger early germination processes, then dried for storage and sowing. Improves germination uniformity, vigor, and crop performance. Methods include osmopriming, matrix priming, and hydropriming.

Seed Treatment with Beneficial Microorganisms

Microbial seed treatment is gaining importance for improving crop growth and managing seed-borne diseases. Legume seeds are commonly treated with Rhizobium, while other microbes like Azospirillum are also being explored. Beneficial organisms such as *Trichoderma, Bacillus, Pseudomonas* and Chaetomium can protect seeds from pathogens. Techniques like biopriming, osmopriming, drum priming, and seed coating ensure uniform application and enhance effectiveness. Although challenges like formulation, quality control and cost limit large-scale adoption, microbial seed treatments remain a sustainable and eco-friendly alternative to chemical control, promoting healthier seeds and seedlings.

Conclusion

Seed treatment is a vital tool for improving seed quality, protecting against pests and diseases, and enhancing crop performance. A range of methods including chemical, biological, physical, and advanced mechanical techniques like coating and pelleting offer solutions suited to different crops and farming systems. Modern approaches, such as seed priming and biopriming, further enhance germination, seedling vigor, and stress tolerance. Adoption of appropriate seed treatment strategies not only ensures better crop establishment and yield but also promotes sustainable and environmentally friendly agricultural practices.

References

Agboola, D. A. (2003). Effect of plant growth hormones and thiourea on seed germination of *Ceiba pentandra* and *Terminalia suparba*. *Journal of Tree Science*, 22(1&2): 76-78.

Agrios, G. N. (2005). Plant Pathology. Fifth Edition, Elsevier Academic Press, California, London-U.K. Publisher: Dana Dreibelbis, pp. 922.

Aladjadjiyan, A. (2007). The use of physical methods for plant growing stimulation in Bulgaria. *Journal of Cental Europian Agriculture*, 8(3): 369-380.

Anderson, J. D., Triplett, L. L., Haber, A. H., Meyer, H. and Mayer, A. M. (1973). Dichloro-methane and lettuce seed germination. *Science*, 179(4068): 94-96.

Baker, K. F. (1969). Aerated-steam treatment of seed for disease control. *Horticulture Research*, 9: 59-73.

Arias-Rivas, B. (1994). Evaluation of seed coating treatment on maize (*Zea mays)* stand establishment and seed rot caused by *Pythium spp*. at early planting season. PhD. Diss. Iowa State University, Ames, IA, U.S.A

ASF (2010). National code of practice for the use of seed treatments. Australian Seed Federation Limited, pp.1-7. Retrieved: September 4, 2014 from http://www.asf.asn.au/userfiles

Bacon, J. R., Brocklehurst, P. A., Gould, A., Mahon, R., Martin, N. C. J. and Wraith, M. J. (1988). Evaluation of a small scale fluidized bed seed treatment apparatus. Application to Seeds and Soil, Mono. 39, BCPC, Thornton Health, UK. pp. 237-243.

Banks, H. J. (1998). Prospects for seed disinfestations.Proceedings of the Australian Postharvest Technical Conference Canberra, 26-29 May 1998

Bel'skii, A. I. and Mazulenko, N. N. (1984). Effects of presowing treatment of barley seeds on the incidence of fungal diseases on the plants. *Mikologiya Fitopatologiya*, 18: 312-316.

Bennett, M. A., Grassbaugh, E. M. and Evans, A. E. (2013). Vegetable crop seed vigor and seedling performance. *Acta Horticulturae*, 975: 172-179.

Bennett, M. A., Fritz, V. A. and Callan, N. W. (1992). Impact of seed treatments on crop stand establishment. *Horticulture Techno-logy*, 2: 345-349.

Ebrahimi, R., Ahmadizadeh, M. and Rahbarian, P. (2014). Enhancing stand establishment of tomato cultivars under salt stress condition. *South Western Journal of Horticulture, Biology and Environment*, 5(1): 19-42.

Elwakil, M. A. (2003). Use of antioxidant hydroquinone in the control of seed-borne fungi of peanut with special reference to the production of good quality seed. *Plant Pathology Journal*, 2: 75-79.

Harman, G. E. (1991). Seed treatments for biological control of plant disease. *Crop Protection*, 10: 166-171.

Hall, T. J. and Taylor, G. S. (1983). Aerated-steam treatment for control of Alternaria tenuis on lobelia seed. *Annals of Applied Biology*, 103: 219-228.

Golezani, K. G. (2013). Seed priming and field performance of borage (*Borago officinalis* L.) under different irrigation treatments. *International Journal of Agronomy and Plant Production*, 4: 82-87

Hung, P. E., Fritz, V. A. and Waters, L. Jr. (1992). Infusion of shrunken-2 sweet corn seed with organic solvents: effects on germination and vigor. *Horticulture Science*, 27(5): 467-470.

Luthra, J. C. and Sattar, A. (1934). Some experiments on the control of loose smut, *Ustilago tritici* (Pers.) Jens. of wheat. *Indian Journal of Agricultural Science*, 4: 177-199.

Maude, R. B. (1996). Seedborne diseases and their control: Principles and practices. CAB International, Walling ford, U. K. 280 pp.

Natural Plant Extracts as Bio-preservatives: A Sustainable Approach in Post-Harvest Technology

Farhat Umra and Ayushi Negi

Abstract

India's agricultural sector suffers significant post-harvest losses, particularly for fruits and vegetables (estimated at 16% overall, with economic losses over ₹92,651 crores annually). Guava (15.05%) and tomato (12.84%) lead these losses, highlighting the urgent need for sustainable preservation. Natural plant extracts, such as neem, moringa, turmeric, and Lamiaceae essential oils, offer a promising, chemical-free solution due to their inherent antimicrobial and antioxidant properties. These bio-preservatives work by disrupting pathogen membranes, inhibiting enzymes, and scavenging radicals. Application via coating, dipping, or edible films shows efficacy in Indian conditions. Strategies for small-scale farmers include low-cost extraction and integration with cold storage, offering a sustainable path to reduce losses and minimize synthetic chemical use.

Introduction

India, the world's second-largest producer of fruits and vegetables (over 334 million tonnes), suffers staggering post-harvest losses (5-25%), translating to economic damage exceeding ₹92,651 crores annually. Commodities like guava (15.05%) and tomato (12.84%) are hit hardest. India's tropical climate accelerates microbial spoilage, necessitating effective preservation. Traditional synthetic chemical methods raise health and environmental concerns. To address this, natural plant extracts emerge as a vital, sustainable solution. Rooted in ancient Indian texts (Charaka Samhita), modern science validates their potent antimicrobial and antioxidant properties, providing an effective, consumer-accepted alternative to significantly extend the shelf life of perishable commodities.

Mechanisms of Action

Plant extracts act as effective bio-preservatives through three mechanisms:

Antimicrobial Activity: Essential oils (thymol, carvacrol) and phenolics disrupt microbial cell membranes. Neem extract inhibits enzyme systems, confirmed by 20% neem's strong inhibition of *Aspergillus niger*. Moringa controls soft rot bacteria like *Erwinia carotovora*.

Antioxidant Properties: Phenolic compounds and ascorbic acid scavenge free radicals, preserving produce color, texture, and nutrition. Guava leaf extract reduces lipid peroxidation in tomatoes; Citrus peel extracts prevent oxidative browning.

Enzyme Inhibition: Extracts inhibit deterioration enzymes. Turmeric (curcumin) strongly inhibits Polyphenol oxidase (PPO), preventing enzymatic

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browning and maintaining quality.

Effective Plant Extracts for Indian Conditions

Neem (*Azadirachta indica*): Widely available, neem contains azadirachtin with systemic antifungal activity. 5-20% aqueous extract significantly extends the shelf life of mangoes, bananas, and citrus fruits by 7-12 days under ambient conditions. Application is by dipping or spray coating.

Moringa (*Moringa oleifera*): Leaves contain glucosinolates and phenolic acids providing excellent antimicrobial/antioxidant properties. 10-20% aqueous leaf extract controls post-harvest decay in tomatoes, extending shelf life by 40-50%, maintaining firmness and reducing weight loss.

Turmeric (*Curcuma longa*): Curcumin in the extract shows strong antifungal activity against pathogens like *Alternaria alternata* and anti-browning properties. Effective concentration is 2-5% w/v (rhizome powder) or 0.1-0.5% v/v (essential oil).

Essential Oils (Lamiaceae Family): Thyme (rich in thymol), oregano (rich in carvacrol), and mint oils offer high concentrations of antimicrobial compounds. They are best used in nanoemulsions or edible coatings to control volatility and improve persistence.

Aloe Vera (*Aloe barbadensis*): The gel forms excellent edible coatings, creating a semi-permeable barrier that reduces moisture loss. Aloe vera coating extends the shelf life of grapes, strawberries, and tomatoes by 2-3 weeks under refrigerated conditions.

Application Methods for Small-Scale Farmers

Successful implementation of natural plant extracts requires practical, cost-effective application methods suitable for Indian farming conditions.

Method	Description
Coating and Dipping	Fresh produce dipped in plant extract solution for 2-5 min, then air dried before packaging.
Edible Film Incorporation	Plant extracts added to biodegradable films (chitosan, pectin, starch) acting as physical barrier + active preservative.
Spray Applications	Uniform spray coverage, good for irregularly shaped produce. Nano-emulsions of essential oils increase stability and effectiveness.
Packaging Integration	Extracts incorporated into packaging materials or sachets inside storage containers, providing slow, continuous release of active compounds.

Integration with Existing Preservation Methods

Natural plant extracts work synergistically with conventional preservation techniques, enhancing overall effectiveness while reducing reliance on synthetic chemicals.

Preservation Method	**Integration with Plant Extracts**
Cold Storage Integration	Neem-treated mangoes stored at 8°C show 25-30 days shelf life vs. 15-20 days untreated.
Modified Atmosphere Packaging (MAP)	Essential oil-incorporated films in MAP provide extra antimicrobial protection for leafy vegetables and soft fruits.
Traditional Methods Enhancement	Plant extracts enhance sand storage (roots) and bamboo basket storage (fruits) by reducing pests and pathogens.

Challenges and Limitations

Standardization Issues: Variability in plant extract composition due to seasonal, genetic, and environmental factors necessitates the development of standardization protocols for commercial applications.

Shelf Life of Extracts: Limited shelf life of many plant extracts requires effective preservation methods and the development of stable formulations remains a key research priority.

Scale-up Challenges: Scaling up from laboratory to commercial applications presents technical challenges across extraction, formulation, and application methods.

Regulatory Frameworks: Clear regulatory guidelines for natural preservatives in food applications are needed to facilitate commercial adoption.

Conclusion

Natural plant extracts are a sustainable solution for India's post-harvest losses. Locally available neem, moringa, and turmeric offer proven antimicrobial alternatives to synthetics, aligning with consumer demand. Coordinated effort and investment are needed to accelerate adoption, leading to economic benefits and positioning India as a global leader in green preservation.

References

Yarmolinsky, L., Nakonechny, F., Haddis, T., Khalfin, B., Dahan, A. and Ben-Shabat, S. (2024). Natural Antimicrobial Compounds as Promising Preservatives: A Look at an Old Problem from New Perspectives. *Molecules*, 29(24): 5830.

Palei, S., *et al.* (2024). Efficacy of Plant Extracts to Prolong Shelf Life: A Study on Neem and Turmeric in Preservation of Mango (*Mangifera indica* L.). *Journal of Advances in Biology & Biotechnology*, 27(11): 1698.

Wang, Y., Shaukat, M., Farhan, M. and Pan, J. (2025). Role of essential oil nanoemulsion and biopolymer-based edible coatings on postharvest quality preservation of fruits and vegetables during cold storage. *Journal of Horticultural Science and Technology*, 25(8): 1001.

Ewekeye, T., *et al.* (2024). Effects of Neem, Moringa and Synthesized Silver Nanoparticles Coating on Postharvest Shelf Life and Quality Retention of Tomato (*Solanum lycopersicum* L.). *European Journal of Nutrition & Food Safety*, 16(7): 1454.

Orădan, A. C., Tocai, A. C., Rosan, C. A. and Vicaş, S.I. (2024). Fruit Extracts Incorporated into Meat Products as Natural Antioxidants, Preservatives, and Colorants. *Processes*, 12 (12): 2756.

Kaur, J. and Borah, A. (2021). Application of bacteriocins and aloe vera gel as biopreservatives in edible coatings to extend the shelf life of fruits and vegetables: A review. *The Pharma Innovation Journal*, 10 (4): 6176.

Gidagiri, P., Lekshmi, P. R. G. and Shameena, S. (2025). Nanoparticle-Enriched Edible Coatings with Plant Extracts and Essential Oils for Extending Postharvest Quality of Fruits and Vegetables. *Journal of Advances in Biology & Biotechnology*, 28(1): 1881.

Seed Germination Test

Shwetha, Subhashini and Cholan

Abstract

Alright, let's not kid ourselves germination testing is basically the unsung hero of agriculture. Farmers, scientists, and seed companies all obsess over it, and for good reason. It tells you straight-up: out of a pile of seeds, how many are actually going to grow into decent plants when life treats them well. This whole process is the backbone for making sure crops don't flop, and that what's on the label isn't just wishful thinking. In this write-up, we're digging into why we bother with germination tests, what makes them tick, how they're done, what messes them up, how we judge the results, and why any of this matters for seed certification and breeding better crops.

Introduction

You know that moment when you toss a handful of seeds into the dirt and hope for the best? Germination is where the magic happens or doesn't. It's literally the starting line for every plant out there. If a seed can't germinate, it's just bird food. Scientists run germination tests in labs to see how many seeds in a batch will actually sprout when given primo conditions think perfect temperature, moisture, light, the works. These tests aren't just busywork; they're a sneak peek at how a seed lot might perform in the real world. Pretty much every seed lab on the planet follows strict playbooks from ISTA or AOSA, so there's no funny business. This isn't just about sprouting beans in a jar for kicks it's about keeping seed quality up, making sure farmers don't get ripped off, and protecting crop genetics. When you see a germination percentage on a seed bag? Yeah, that number comes from this testing.

Objectives of Germination Test

- ✓ Find out how many seeds are actually alive and kicking.
- ✓ Judge how tough the seeds are and whether they'll pop up in the field.
- ✓ See how long seeds will last in storage without turning into duds.
- ✓ Get the goods for certification and those little quality labels you see on bags.
- ✓ Give breeders and researchers something solid to work with.

Principle of Germination Test

The basic idea? If it's a good seed, it'll sprout

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when you give it what it wants water, warmth, air, maybe some light. Simple, right? The test is all about seeing how many seeds turn into healthy seedlings in a set time, under controlled conditions. Both inside (like, is the seed too old or stuck in dormancy?) and outside factors (temperature, moisture, oxygen, etc.) can make or break it.

The magic formula, by the way:

Germination Percentage = (Number of normal seedlings / Total seeds tested) × 100

Materials and Methods

What You Need

- ✓ A batch of seeds (not just any handful, but a sample that actually represents the lot)
- ✓ Something for them to sprout on paper, sand, or soil
- ✓ Clean water (distilled, not from your tap if you can help it)
- ✓ Trays or boxes to keep things tidy
- ✓ A snazzy incubator or germinator to keep the temperature just right
- ✓ Forceps, labels, markers the nerd stuff

How It's Done

Sampling: Grab 400 seeds (yep, 400 it's the rule) from your batch.

Setting the Stage: Pick your substrate paper towels, sand, whatever floats your boat (as long as it's official).

Waterworks: Wet the substrate evenly. Not a swamp, just moist.

Seed Placement: Spread the seeds out so they're not all on top of each other. Cover them up if you're using paper or sand.

Incubation: Stick the trays in the germinator. Different seeds, different settings. Like, cereals love 25°C, but legumes are more flexible (20-30°C).

Daily Check: Take a look each day, or as per the rulebook.

Final Tally: After a week or two (7-14 days, usually), count up the winners.

Crunch the Numbers: Calculate the percentage of seeds that grew into normal seedlings.

Reading the Results

Seedlings get sorted into three buckets:

Normal: Good to go, will probably grow into a proper plant.

Abnormal: Sprouted, but... something's not right (missing roots, funny stems, that sort of thing).

- Dead: No signs of life, not even a zombie seed.

You don't just throw out a number. You gotta say how long you waited and the test conditions, like: Germination: 92% (10 days at 25°C, paper towel method).

Stuff that Messes With Germination Tests

Water: Seeds need a Goldilocks situation not too wet, not bone dry. Just enough to get those enzymes jazzed up.

Temp: Every plant's got its sweet spot. You can't expect lettuce to sprout in a sauna or cacti to love the fridge.

Oxygen: Seeds gotta breathe too, you know? No oxygen, no party.

Light: Some seeds are divas and need the spotlight to wake up, others prefer the blackout treatment.

Seed quality: Old, banged-up, or poorly stored seeds? Yeah, they're probably not going to win any sprouting contests.

Nasty germs: Fungus and bacteria can totally crash the germination party and ruin everything.

Why Even Bother Testing Germination?

Quality control: So you don't end up selling (or buying) a bag of duds. Basically, it keeps people honest.

Field prediction: If seeds sprout well in the lab, odds are they'll do alright in the dirt. Not a guarantee, but a good sign.

Rules and regs: Lets the seed police (yes, that's a thing) make sure everyone's playing fair.

Science nerd stuff: Helps breeders and researchers figure out if their new Franken-seed is actually viable.

Storage check: Tells you if your stash is still good or if you need to toss it and start over.

The Catch

Honestly, lab tests are nice and all, but real life is messy. Sometimes seeds ace the lab test and totally flop in the field. Weather, bugs, soil life happens. That's why people double-check with field or vigor tests. Trust, but verify, right?

Wrapping it Up

Bottom line: Germination testing is kind of a big deal if you care about crop yields, not wasting money, or just not getting yelled at by farmers. Do it right, follow the rules (ISTA or whoever's in charge), and you'll actually know if your seeds are worth planting. Skip it, and you're rolling the dice.

References

AOSA. (2019). Rules for Testing Seeds. Washington, D.C.

Bewley, J. D. and Black, M. (2012). Physiology and Biochemistry of Seeds in Relation to Germination. Springer.

Copeland, L. O., & McDonald, M. B. (2017). Principles of Seed Science and Technology (5th ed.). Springer.

ISTA. (2020). International Rules for Seed Testing. Zurich.

Sadjad, S. (2013). Seed Viability and Vigor. Tehran University Press.

Wide Hybridization

S. Dharshini, S. Subashini and K. Chozhan

Introduction

Wide or distant hybridization involves crossing genetically diverse individuals either from different species within the same genus (interspecific) or from entirely different genera (intergeneric). Although many such hybrids face challenges like sterility or poor adaptability, they are important in plant breeding for introducing beneficial traits such as resistance to diseases, environmental stress tolerance, and improved crop quality. Noteworthy examples include Triticale a productive wheat and rye hybrid and Raphano-brassica, a radish and cabbage hybrid that, despite being amphidiploid, lacked practical application. The earliest known wide hybrid was Fairchild's Mule, created in 1717 by crossing carnation and sweet william. Today, wide hybridization continues to contribute significantly to advancements in both agriculture and ornamental horticulture.

What is hybridization?

Hybridization between individuals from different species belonging to the same genus or two different genera, is termed as distant hybridization or wide hybridization, and such crosses are known as distant crosses or wide crosses.

Inter specific hybridization: This is the process of crossing individuals from two different species within the same genus. It is used to combine desirable traits from both species, although it may face issues like partial fertility or incompatibility.

Nerica, an upland rice for Africa

Oryza sativa (Asian upland rice): non-shattering, resistant to lodging, high yield potential

Oryza glaberrima (African rice): drought tolerant, disease resistant, weed suppressing

Nerica rice combines the best of both species.

AFRICAN RICE

NERICA RICE

ASIAN RICE

Inter generic hybridization: This involves crossing individuals from two different genera. It is more complex due to greater genetic differences, and

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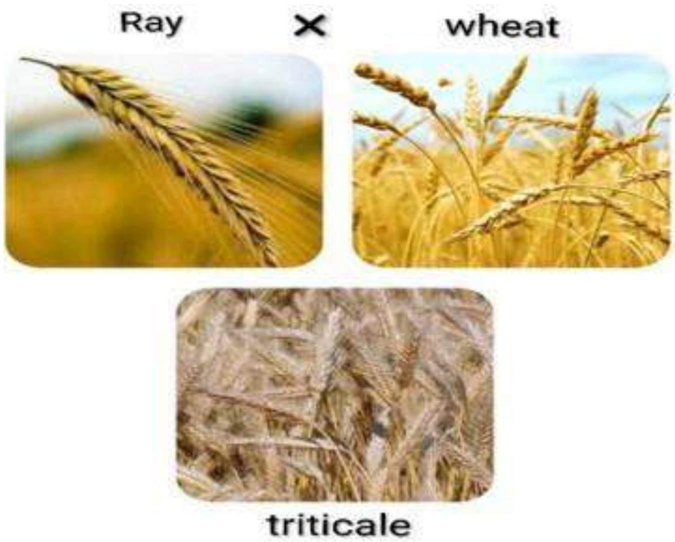
resulting hybrids are often sterile or non-viable.However, successful cases can lead to new crop varieties with valuable traits. Example: Wheat × Rye → Triticale.



Objectives of wide hybridization

- ✓ Introduction of beneficial traits from wild relatives that are missing in cultivated crops. Example: Resistance to diseases and insect pests.
- ✓ Improved adaptability to environmental stresses such as drought, cold, or salinity.
- ✓ Enhancement of quality traits, such as better fibre quality in cotton.
- ✓ Increase in crop yield, seen in crops like oats, tobacco, maize, and sugarcane.
- ✓ Incorporation of specific traits, including cytoplasmic male sterility (CMS), early maturity, dwarfism, and other desirable morphological features.
- ✓ Utilization of hybrid vigor (heterosis) in vegetatively propagated or ornamental plants for enhanced growth and performance.
- ✓ Extension of growth or flowering periods, such as longer vegetative or blooming phases.
- ✓ Development of new genetic types, including novel species or F_1 hybrids that do not naturally occur.

Barriers to the production of distant hybridization

Failure of Zygote Formation / Cross Incompatibility: Cross incompatibility refers to the inability of functional pollen from one species or genus to successfully fertilize the female gametes of another species or genus.

This incompatibility may occur due to the following reasons:

Failure of fertilization: The pollen may not germinate on the stigma.

Pollen tube growth issue: The pollen tube may fail to reach the embryo sac, preventing sperm cells from achieving fertilization.

Pollen tube bursting: The pollen tube may rupture within the style of a different species.

Length mismatch: If the style of the female parent is longer than the normal growth length of the pollen tube, the pollen cannot reach the embryo sac.

Pollen tube thickness: Pollen tubes of polyploid species are generally thicker than those of diploid species.

Growth rate difference: when a diploid is the female parent and a polyploid is the male parent, the polyploid pollen tube grows slower in the diploid style than it would in a polyploid style.

Failure of Zygote Development / Hybrid Inviability

Hybrid inviability refers to the inability of a hybrid zygote to develop into a normal embryo under normal growth conditions.

This may happen due to the following reasons:

Lethal genes: Presence of harmful genes that cause death of the embryo.

Genetic disharmony: incompatibility between the genetic material of the two parents.

Chromosome elimination: loss of chromosomes during cell division in hybrid embryos.

Incompatible cytoplasm mismatch between the nuclear and cytoplasmic components.

Endosperm abortion failure of endosperm development leading to embryo death.

Failure of Hybrid Seedling Development / Hybrid Sterility

Some distant hybrids fail to survive during seedling growth or even after flowering begins. The main reason for this failure is usually the presence of complementary lethal genes.

Example: In cotton, certain interspecific hybrids appear normal at first but die at different stages of seedling development, and some may die at the flowering stage.

Hybrid sterility:

Hybrid sterility refers to the inability of a hybrid to produce viable offspring. The main cause of hybrid sterility is lack of structural homology between the chromosomes of two species.

Techniques for production of distant hybrids:

Choice of parents

- ✓ Pollinating sufficiently large no. of flowers.
- ✓ Reciprocal crosses
- ✓ Determine the barrier and then take measures to overcome it:
- ✓ Bridge crosses
- ✓ Use of pollen mixtures
- ✓ Manipulation of pistil
- ✓ Use of growth regulators IAA; NAA; 2,4-D and GA_3 etc.
- ✓ Large number of crosses
- ✓ Protoplast fusion
- ✓ Embryo culture
- ✓ Grafting

Applications of Wide Hybridization in Crop Improvement

Alien Addition Lines: Contain an extra chromosome pair from another species, added to the normal chromosome set of the crop.

Alien Substitution Lines: Have one chromosome pair from a different species that replaces a corresponding chromosome pair of the parent species.

Introgression of Genes

Involves the transfer of small chromosome segments carrying useful genes such as:

- ✓ Disease resistance
- ✓ Wider adaptability
- ✓ Improved quality
- ✓ Male sterility
- ✓ Self-incompatibility (SI)
- ✓ Higher yield and other desirable traits

Development of New Crop Species: Creation of entirely new crop species through hybridization.

Example: Triticale (a hybrid between wheat and rye)

Development of New Hybrid Varieties: Used for producing F_1 hybrids combining desirable traits from different species.

Example: Varalaxmi cotton (*G. hirsutum* × *G. barbadense*)

Example: Sugarcane modern commercial varieties are complex interspecific hybrids involving *S. officinarum* and *S. spontane.*

Limitations of Distant Hybridization

Cross Incompatibility: Failure of successful fertilization.

F_1 Sterility: Hybrids often sterile.

Difficulty in New Species Formation

Lack of Chromosome Homoeology: Chromosomes from parents don't pair properly.

Undesirable Linkages: Unwanted traits may transfer together.

Trouble Transferring Recessive or Quantitative Traits

F_1 Non-flowering: Hybrids may not flower.

Limited Use of Improved Varieties

Seed Dormancy Issues

Hybrid varieties

Upland cotton MCU-2, MCU-5, Khandwa1, Khandwa2 etc are derivatives of interspecific hybridization.Hybrid between Pearl millet x Napier grass Hybrid Napier which is very popular for its high fodder yield and fodder quality e.g. Jaywant and Yashwant.

Interspecific hybrids in cotton- Varlaxmi, Savitri, DCH-32, NHB-12, DH-7, DH-9 etc.

Prabhani Kranti variety of bhindi

Conclusion

Wide hybridization is an important method in crop improvement, enabling the transfer of beneficial traits such as disease resistance, better quality, and adaptability between species. Although challenges like incompatibility and sterility exist, advanced techniques like embryo culture and protoplast fusion make it highly effective for creating improved varieties and new crops

References

Acosta A. C. (1962). The transfer of stem rust resistance from rye to wheat. Diss. Abst. 23: 34.

Alonso L. C. and G. Kimber, (1980). A hybrid between diploid *Agropyron junceum* and *Triticum aestivum*. Cereal Research Communication 8: 355-358.

Elbern, B. (1981). Möglichkeiten der Bastardierung zwischen Gerste, Weizen und Roggen. Diss Landw Fak Universität Bonn

Bates, L. S., Mujeeb, A. K. and Waters, R. F. (1976). Wheat x barley hybrids Problems and potentials. *Cereal Research Communication*, 4: 377-386.

Bates, L. S. and Deyoe, C. D. (1973) Wide hybridization and cereal improvement. *Economic Botany*, 27: 401-412.

Bates, L. S., Campos, V. A., Rodriguez, R. and Anderson, R. G. (1974) Progress towards novel cereal grains. *Cereal Sic Today*, 19: 283-286.

Ackhouse O. W. (1916). Note on inheritance of crossability. *Journal of Genetics*. 6: 91-94.

Caldwell, R. M., J. F. Schafer, L. E. Compton and F. L. Patterson. (1956). Resistance to leaf rust derived from Agropyron elongatum. Rept. 3rd Intl. Wheat Rust Conf., p. 95-96.

Cauderon, Y. (1966). Genome analysis in the genus Agropyron. Proceedings of 2nd Internatuional Wheat Genetics Symposium, Lund, Sweden, p. 218-234.

Handling of Segregating Population: Pedigree Method

A. Jeevitha, S. Subashini and K. Chozhan

Introduction

The main objective of plant breeding is to create improved crop varieties that offer high yield along with favorable agronomic and quality traits. Achieving this requires careful management of segregating populations groups of plants that show genetic variation due to gene recombination and segregation following hybridization. Proper management of these populations is crucial for identifying and selecting superior individuals that possess the desired combination of traits. Among the different breeding techniques, the pedigree method is particularly important for self-pollinated crops. This method involves systematic selection of plants along with meticulous record-keeping of their ancestry over successive generations. Maintaining accurate records allows breeders to track the origins of selected lines, understand the inheritance of key traits, and make more informed selection decisions. In the pedigree method, handling segregating populations demands careful observation, precise data recording, and thorough evaluation of each generation, beginning with the F_2 generation. Early generations focus on identifying plants with favorable traits, while later generations emphasize assessing the stability, uniformity, and overall performance of selected lines. By following this structured approach, breeders can effectively combine desirable genes from different parents and develop high-performing, genetically stable varieties suitable for varied environments.

Pedigree method: The pedigree method involves selecting individual plants from the F_2 generation onwards and tracking their progeny. A detailed record of parent-offspring relationships is maintained, known as a pedigree record. Selection continues until the progeny shows no further segregation, indicating genetic stability. At this stage, selection is made among the progeny lines, as there is no genetic variation within them. This process allows breeders to identify and select superior lines with desired traits.

Pedigree record: A pedigree can be defined as a record detailing an individual's ancestry, typically tracing back several generations. It outlines the lineage, including the parents, grandparents, great-grandparents, and further forebears of the individual.

Maintenance of Pedigree Record: Pedigree records can be maintained in various ways, but they should always be straightforward and precise.

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Typically, each cross is assigned a unique number. The first two digits indicate the year the cross was made, while the remaining digits represent the serial number of that cross within that year. For instance, the number 7911 represents the 11th cross conducted in the year 1979. In segregating generations, one of two designation systems may be used.

System I: In this method, progenies of individual plants in each generation are assigned row numbers corresponding to their position in the field. Additionally, for F_4 and later generations, each progeny is given the row number of the progeny from the previous generation from which it originated.

System-II: In this approach, selected plants in each generation are given serial numbers within their respective progenies. Every progeny or selected plant carries the serial numbers of the plants from the previous generation to which it is directly related. For example, plants chosen in the F_2 generation receive the serial numbers of their parent F_1 plants. Similarly, plants selected from an F_3 progeny inherit the number of that progeny, and in every generation, each selected plant is also assigned its own unique serial number.

Procedure for pedigree method

Hybridization: Choosing the parents for a cross is a critical step in any hybridization-based breeding program. These selected parents are then crossed to create either a simple or a complex hybrid. For simplicity, the seeds produced from these simple or complex crosses are referred to as F_1 seeds.

F_1 Generation: F_1 seeds are planted with sufficient spacing to allow each plant to produce the maximum number of F_2 seeds. Typically, 15-30 F_1 plants provide enough seeds to establish a well-sized F_2 population.

F_2 Generation: In the F_2 generation, typically 2,000-10,000 plants are planted with spacing to allow for effective selection. From this population, around 100-500 plants are chosen, and their seeds are harvested individually. Generally, the F_2 population should be 10-100 times larger than the number of plants intended for selection. The exact number of selected plants, ranging from 100-500, depends on the available resources and the goals of the breeding program. When the aim is to improve yield, a larger number of F_2 plants is usually selected. Selection at this stage focuses on traits that are simply inherited, such as plant height, head type, seed color, disease resistance, and the presence of awns. Selecting plants based on vigor is usually not effective, as vigor may result from heterozygosity, environmental effects, or genotype-by-environment interactions.

F_3 Generation: In the F_3 generation, the number of plants chosen should ideally be fewer than the number of F_3 progenies. If only a small number of superior progenies exist, the entire cross might be discarded.

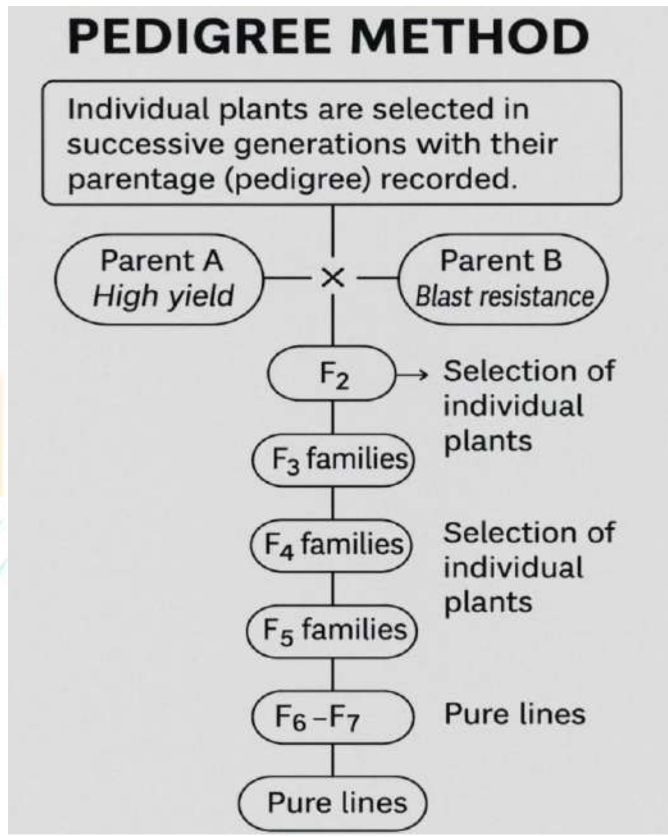
F_4 Generation: Individual plant progenies are planted with proper spacing, and selection is primarily made from the superior progenies. The number of plants chosen in the F_4 generation is usually much smaller than in the F_3 generation, while plants with defects or undesirable traits are discarded. If two or more progenies derived from the same F_3 progeny are similar and comparable, only one is selected from the superior progenies.

F_5 Generation: Individual plant progenies are usually planted according to the recommended commercial seed rate. Multiple rows are often grown for each progeny to allow better comparison when many progenies are grown in bulk. In progenies exhibiting segregation, selection can be made at the individual plant level. The number of progenies is then reduced to a manageable size for preliminary yield trials, typically ranging from 25 to 100 progenies.

F_7 Generation: Individual plants are grown in multi-row plots and assessed visually. By this stage, progenies are usually harvested in bulk as they are nearly homozygous. In progenies that show exceptional performance, individual plants may be selected. Preliminary yield trials are typically conducted in the F_6 generation for progenies that are sufficiently homozygous and have adequate seed. Progenies with poor performance are discarded based on yield results from these trials.

F_8-F_{10} Generation: The best-performing lines are assessed in replicated yield trials across multiple locations. During these trials, the lines are evaluated for traits such as yield, disease resistance, lodging resistance, maturity duration, and quality. Any line that outperforms the commercial variety used as a check in the trial may be selected for release as a new variety based on its superior yield and other characteristics.

F_{11} Generation: When a strain is considered suitable for release as a variety, the breeder typically multiplies its seed during the final year of testing. The breeder is responsible for providing the breeder seed, which is then used to produce foundation seed. Consequently, from F_1 to F_{12}, the seeds of the new variety are multiplied to ensure sufficient supply for farmers.



References

Chen, X. and Lee, J. (2020, September). The identification and selection of good quality data using a pedigree matrix. In Sustainable Design and Manufacturing 2020: Proceedings of the 7th International Conference on Sustainable Design and Manufacturing (KES-SDM 2020) (pp. 13-25). Singapore: Springer Singapore.

Branch, W. D., Kirby, J. S., Wynne, J. C., Holbrook, C. C. and Anderson, W. F. (1991). Sequential vs. pedigree selection method for yield and leafspot resistance in peanut. *Crop Science*, 31(2): 274-276.

Fjalestad, K. T. (2005). Selection methods. In Selection and Breeding Programs in Aquaculture (pp. 159-171). Dordrecht: Springer Netherlands.

Seed Health Testing

Rubitha, Subhashini and Cholan

Abstract

Alright, let's talk about seed health testing, because honestly, it's a big deal if you want your crops to not suck. You can't just eyeball a bag of seeds and call it good sometimes, nasty stuff like fungi, viruses, bacteria, or those little jerk nematodes are hitching a ride. If you want decent germination and crops that don't flop, you gotta make sure the seeds are clean. Farmers and seed nerds run all kinds of tests for this exact reason. This article? It's basically your cheat sheet on why seed health testing matters, how it's done, and why your food security depends on it. Let's get into it.

Introduction

Seeds are kind the OG of farming nothing starts without them. But here's the kicker: even if they look perfect, seeds can be hiding all sorts of microscopic troublemakers. We're talking about stuff that can wipe out a crop before you even know what hit you. That's why testing seeds for health isn't just some nerdy science thing it's survival. You've got fungi like Alternaria or Fusarium, bacteria like Xanthomonas (try saying that five times fast), viruses, nematodes, the whole villain squad. With proper testing, you figure out what's lurking inside and decide if you need to treat, toss, or store those seeds.

Why Bother with Seed Health Testing?

Stop Diseases before they Start: Catching bugs early means you're not fighting a losing battle in the field.

Better Germination: Sick seeds don't sprout well. Duh.

Certification Stuff: Gotta play by the rules if you want those shiny certification stickers.

Trade without Drama: Other countries don't want your seed-borne plagues, so you better check before you ship.

Storage: Infected seeds rot or spread funk during storage. No thanks.

Go Green: Less chemicals, more smart prevention your wallet and the planet will thank you.

The Usual Suspects: Seed-Borne Pathogens

Fungi: The classics. *Fusarium*, *Aspergillus*, *Alternaria*... all the fun guys (get it?) that cause rot, ugly spots, and general plant sadness.

Bacteria: Stuff like *Xanthomonas or Pseudomonas* these can sneak in and wreck your crop from the inside.

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Viruses: *Tobacco Mosaic Virus*, *Bean Common Mosaic Virus*… these little punks hitch a ride and infect future generations.

Nematodes: Tiny worms like *Anguina tritici*. Not cute, not helpful, just there to ruin your day and your germination rates.

How do You Actually Test Seeds?

Pick your weapon, depending on what you're looking for:

Visual Inspection: Just what it sounds like look for weird colors, mold, anything suspicious.

Blotter Method: Stick seeds on wet paper, wait, and then check under a microscope for fungal growth. Kinda old school, but it works.

Agar Plate Method: Seeds go on a nutrient gel, whatever's hiding will grow out and you can ID it.

Washing Test: Give 'me a bath, then look at the wash water under a microscope to spot any free-loaders.

Serological Methods (ELISA): Think "CSI for seeds" using antibodies to spot viruses.

Molecular Methods (PCR): Super high-tech. Look for the pathogen's DNA. If it's there, it's busted.

Grow-Out Test: Plant some seeds, see what happens. If the plants get sick, well, there's your answer. And that's the basics sure, there's way more detail if you wanna go down the rabbit hole, but hey, now you've got the gist. Don't skip seed health testing unless you love surprises (the bad kind).

How Seed Health Testing Actually Happens

Step one, you gotta grab a decent sample none of that "just a handful" business. Real talk, if your sample isn't representative, you're already off to a bad start. Next, sometimes you gotta scrub those seeds clean. Surface sterilization, if you want to get fancy. Basically: kill off whatever's hitchhiking on the outside. Now, pick your poisoner, method based on which nasty bug or fungus you think you're dealing with. There's no "one size fits all" here. Incubation time! Stick those seeds somewhere cozy so any hidden troublemakers can wake up and show themselves. After that, it's detective mode. Bust out the microscope or get high-tech with molecular tools. Find out what's lurking. Last thing: write it all down and send out your report. Whether it's for certification or just to keep the bosses happy, documentation is king.

What Messes with Seed Health

Honestly, Mother Nature's a bit of a wildcard. If it's muggy and hot, pathogens are having a party. Seeds too damp? Might as well roll out the red carpet for fungi. Stash your seeds in a sweaty, stuffy shed with no airflow, and don't be surprised when things go south. And hey, rough handling or bumpy rides? That's like giving infections an open invitation.

Why this Even Matter

Seed health testing isn't just nerdy lab work. It's the backbone of good farming. Healthy seeds = crops that actually sprout together, grow strong, and don't turn into a petri dish for every disease under the sun. Governments care, seed companies care, anyone who eats food should care. It's about food security and keeping farmers from going broke, plain and simple.

Conclusion

Bottom line: if you want good crops, you need healthy seeds. That means testing isn't just "nice to have" it's essential. Finding and ditching the bad seeds before they hit the field saves headaches (and money) later. Plus, new tech means tests are getting quicker and way more accurate. All this? It keeps the food supply rolling and farms running.

References

Agarwal, V. K. and Sinclair, J. B. (1997). Principles of Seed Pathology. CRC Press.

International Seed Testing Association (ISTA). (2023). International Rules for Seed Testing. ISTA Publications.

Mathur, S. B. and Kongsdal, O. (2003). Common Laboratory Seed Health Testing Methods for Detecting Fungi. Danish Government Institute of Seed Pathology.

Neergaard, P. (1979). Seed Pathology (Vol. 1 & 2). MacMillan Press Ltd.

Maude, R. B. (2012). Seedborne Diseases and Their Control: Principles and Practice. CAB International.

Plant Parasitic Nematodes in Indian Floriculture: A Growing Threat

Pranaya Pradhan and Subhasmita Sahu

Abstract

India's age-old tradition of floriculture has recently transitioned into a commercially viable industry, offering self-employment opportunities and foreign exchange benefits. However, plant parasitic nematodes have emerged as a major constraint, significantly affecting both the quality and yield of ornamental flowers. These microscopic pests not only damage plant tissues directly but also facilitate the invasion of secondary pathogens, such as fungi and bacteria, leading to compounded losses. This review summarizes the major nematode species affecting commercially important flowers like Asiatic lily, carnation, chrysanthemum, gerbera, gladiolus, rose, and tuberose, among others. Notable nematode genera include *Meloidogyne*, *Aphelenchoides*, *Ditylenchus*, and *Pratylenchus*. Sustainable flower production requires integrated nematode management, improved farmer awareness, and continued research into nematode-host interactions.

Introduction

India has a rich history of floriculture, referenced in ancient texts like the *Vedas*, *Ramayana*, and *Mahabharata*. However, only in recent decades has the cultivation of flowers for commercial purposes gained momentum. With over 146,000 hectares dedicated to flower production and around 66.66 million tonnes of output annually, floriculture provides both livelihood opportunities and foreign exchange. The primary flower-producing states include Tamil Nadu, Karnataka, Andhra Pradesh, Maharashtra, and West Bengal. The growing demand for cut flowers, especially under protected conditions (like greenhouses), has increased the intensity of cultivation, making crops more vulnerable to pests, particularly plant parasitic nematodes (phytonematodes).

Importance of Nematodes in Ornamental Crops

Plant parasitic nematodes are microscopic roundworms that attack roots, stems, leaves, and buds of ornamental plants. Their damage leads to growth suppression, discoloration, reduced flower size, and even total crop failure. In monoculture flower cultivation, nematode populations can build up rapidly due to favorable conditions. Notably, nematodes can act as primary pathogens or enhance the effect of secondary pathogens, such as root-rot fungi and wilting bacteria. Worldwide losses due to nematodes in ornamentals are estimated at around 11.1% (Sasser and Freckman, 1987), while in India, precise data is lacking but the problem is significant.

Major Nematode Species and their Effects

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Root-Knot Nematodes (*Meloidogyne* spp.)

Affected crops: Chrysanthemum, carnation, rose, gerbera, gladiolus and tuberose.

Symptoms: Gall formation on roots, yellowing and wilting of leaves, stunted growth, bulb and root rot (e.g., in tuberose).

Yield losses: Up to 31.1% in gerbera; 11-22% in gladiolus.

Foliar Nematodes (*Aphelenchoides* spp.)

Affected crops: Primarily chrysanthemum, zinnia, jasmine.

Symptoms: Chlorotic, vein-limited necrotic lesions on leaves, curling and twisting of stems, pale green to brown discoloration.

Most damaging: Cool, wet seasons and under shade conditions.

Lesion Nematodes (*Pratylenchus* spp.)

Symptoms: Root lesions, rot, stunted growth, early leaf yellowing, poor flower development.

Common in: Carnation, chrysanthemum, rose.

Other Notable Nematodes

Burrowing nematode (*Radopholus similis*): Affects jasmine and orchids; causes root and rhizome decay.

Stem nematode (*Ditylenchus dipsaci*): Especially damaging in tulips.

Diversity across Flower Crops

Flower Crop	Major Nematode Species
Tuberose	*M. incognita, R. reniformis, A. besseyi*
Gladiolus	*M. incognita, P. coffeae, T. nanus*
Chrysanthemum	*A. ritzemabosi, M. javanica, R. reniformis*
Gerbera	*M. incognita, P. coffeae, H. indica*
Carnation	*M. incognita, Criconema, L. elongatus*
Rose	*P. penetrans, M. hapla, Xiphinema* spp.

Infestation levels are often exacerbated by the use of contaminated planting material (bulbs, rhizomes, tubers), poor crop rotation, and absence of soil sterilization.

Challenges in Management

Underreporting: Lack of systematic national-level surveys in India means data on yield losses are scarce.

Monoculture Systems: Continuous cropping without rotation leads to nematode build-up.

Protected Cultivation: Though greenhouses offer ideal growth conditions, they can also create microclimates ideal for nematode proliferation.

Farmer Awareness: Many growers are unaware of nematodes' role in crop failure due to their hidden nature.

Conclusion and Recommendations

Plant parasitic nematodes are significant hidden enemies of Indian floriculture, suppressing flower quality, yield, and export potential. Immediate attention is needed to:

- ✓ Develop Integrated Nematode Management (INM) strategies.
- ✓ Promote clean planting materials and soil health through biofumigation, solarization, and organic amendments.
- ✓ Conduct research into nematode-host-pathogen interactions.
- ✓ Increase awareness and training for farmers to identify symptoms and adopt preventive measures.

Only through a coordinated approach involving research, policy support, and grower education can India maintain and expand its position in the global floriculture market.

Bacillus subtilis: The Friendly Bacterium Powering Science, Agriculture and Industry

Kaliprasad Jena, R. Arutselvan and Sulekha Pradhan

Abstract

Bacillus subtilis is a versatile, gram-positive bacterium widely recognized for its role in science, industry, and agriculture. Naturally found in soil and the gut, it thrives in diverse environments thanks to its ability to form resistant spores. As a model organism, it has shaped our understanding of bacterial genetics, enzyme production, and antimicrobial activity. *B. subtilis* secretes useful enzymes like proteases and amylases, which are harnessed in sectors from food processing to detergents. It also produces natural antibiotics such as surfactin and subtilin, making it an eco-friendly alternative to synthetic pesticides and drugs. Its probiotic properties help maintain gut health in humans and animals. Through genetic engineering, *B. subtilis* is being optimized for cutting-edge applications in biotechnology, including vaccine delivery and bioplastic production. Its safety profile, adaptability, and biochemical potential position it as a key player in sustainable and innovative solutions across various domains (Errington and Wu, 2020; Gu *et al*., 2018; Sumi *et al*., 2015).

Introduction

In the vast microscopic world, *Bacillus subtilis* emerges as a significant bacterium known for its diverse applications in science, biotechnology, agriculture, and healthcare. Commonly found in soil, near plant roots, and within the digestive systems of animals, *B. subtilis* plays a vital role as a model organism for studying bacterial behavior, particularly its ability to produce beneficial compounds and resist harmful microbes (Errington and Wu, 2020). First identified in the 1800s, this bacterium has advanced from being a subject of basic research to becoming an industrially valuable organism for producing enzymes and environmentally friendly products. Its ability to form resilient spores enables it to survive in harsh environments, making it adaptable for use in various settings from agricultural soils to manufacturing plants. As a natural producer of enzymes and antimicrobials, *B. subtilis* contributes to biodegradation and disease resistance, enhancing developments in medicine and agriculture (Gu *et al*., 2018).

Figure 1: Colonies of *Bacillus subtilis* grown on nutrient agar showing dry, irregular, opaque growth

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With modern genetic engineering, its capabilities are continually expanding to address global challenges, including sustainable farming and advanced therapeutic solutions (Gu *et al*., 2018).

Bacillus subtilis: *Bacillus subtilis* is a gram-positive, rod-shaped bacterium first identified by Ferdinand Cohn in 1872, now considered a foundational organism in microbiological research (Errington and Wu, 2020). Commonly found in soil, near plant roots, and in animal intestines, *B. subtilis* contributes to ecosystem nutrient cycling by breaking down organic matter. A defining feature is its ability to form endospores durable, dormant structures that withstand heat, UV radiation, and desiccation making it ideal for studying bacterial survival mechanisms (Errington and Wu, 2020).

Table 1: Key Enzymes Produced by *Bacillus subtilis*

Enzyme	Function	Industrial Application
Protease	Breaks down proteins	Detergents, leather softening, food processing
Amylase	Breaks down starch into sugars	Baking, brewing, bioethanol production
Lipase	Breaks down fats and oils	Dairy processing, biodiesel, detergents
Cellulase	Degrades cellulose	Textile, paper, and biofuel industries
Xylanase	Breaks down hemicellulose (xylan) in plant cell walls	Animal feed, paper bleaching

This bacterium thrives in both aerobic and low-oxygen environments, showcasing remarkable adaptability. It is generally regarded as safe for consumption and is used in fermented foods like natto, where it offers probiotic benefits. Its enzymatic activity enables it to break down proteins, carbohydrates and lipids, adjusting to changing environmental conditions (Gu *et al*., 2018). With a fully sequenced genome containing about 4.2 million base pairs and over 4,000 genes, *B. subtilis* bridges basic research and applied science, making it a valuable tool in biotechnology (Errington and Wu, 2020).

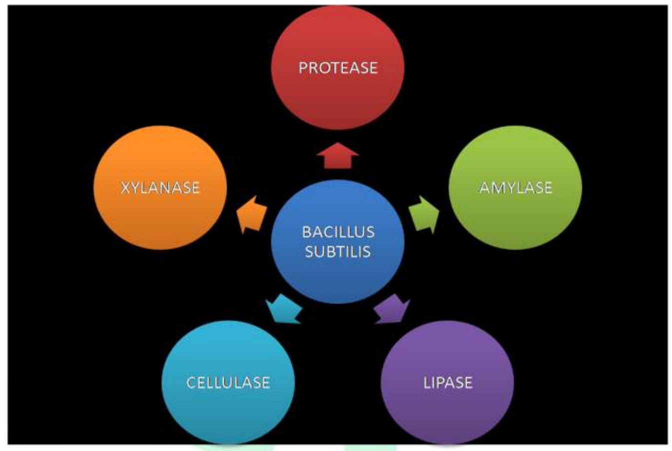

Figure 2: Enzymes produced by *Bacillus subtilis*

How *Bacillus Subtilis* Produces Useful Enzymes and Antibiotics: *Bacillus subtilis* functions as an efficient biological factory for producing enzymes and antimicrobial compounds, with wide applications in industries such as healthcare and cleaning (Gu *et al.*, 2018; Sumi *et al.*, 2015). It utilizes aerobic metabolism to break down available nutrients and responds to environmental cues like nutrient scarcity by releasing extracellular enzymes that target proteins, starches, and lipids. For instance, when starch is detected, *B. subtilis* increases the production of amylases through regulated gene expression, optimizing energy extraction during active growth phases. In industrial settings, it excels in synthesizing proteases used in detergents to break down stains, achieving high yields in bioreactors under controlled conditions.

Table 2: Antimicrobial Peptides Produced by *Bacillus subtilis*

Peptide Name	Mode of Action	Target Organisms	Use Case
Surfactin	Disrupts membrane integrity	Bacteria, fungi, viruses	Biocontrol, biomedical research
Subtilin	Inhibits cell wall synthesis	Gram-positive bacteria	Food preservation, medical research
Bacillomycin	Forms pores in fungal membranes	Fungal pathogens	Agricultural biocontrol
Fengycin	Interferes with fungal membrane permeability	Filamentous fungi	Plant disease control

Its ability to secrete enzymes efficiently allows large-scale production using both solid and liquid fermentation methods. Additionally, during nutrient-limited phases, it generates antimicrobial peptides such as surfactin and fengycin, which disrupt microbial membranes or inhibit cell wall synthesis. These compounds are valuable in agriculture for pest control and veterinary treatments. Their biosynthesis is directed by specific gene clusters that incorporate structural variations for improved effectiveness, highlighting *B. subtilis*'s potential as a sustainable tool for biotechnology.

***Bacillus subtilis* Vs. Pathogenic Bacteria: A Natural Fighter:** *Bacillus subtilis* plays a vital role in combating harmful bacteria, acting as a natural defender and health enhancer with fewer side effects than synthetic drugs (Sumi *et al.*, 2015). It produces antimicrobial peptides such as cyclic lipopeptides that can disrupt bacterial membranes or inhibit cell wall synthesis in Gram-positive pathogens like foodborne contaminants. Lipid-based compounds like surfactin further contribute by breaking down enemy cell membranes, leading to cell leakage and death. Beyond direct antimicrobial action, *B. subtilis* competes for nutrients and space, outpacing harmful microbes in environments such as soil and the gut. It also forms biofilms that physically block invaders and release growth-promoting signals for the host. In agriculture, it suppresses mold and bacterial diseases, enhancing plant health naturally. In animal care, it balances gut microbiota and strengthens immune responses, with durable spores surviving digestion to activate protective mechanisms. Unlike synthetic antibiotics, it reduces the risk of resistance due to its multi-target strategies and environmental safety, making it a sustainable alternative for long-term microbial control.

The Future of Friendly Bacteria: Genetic Engineering and *Bacillus Subtilis*: Genetic engine-ering is increasingly expanding the capabilities of *Bacillus subtilis*, making it a versatile organism for advanced applications across various sectors (Gu *et al.*, 2018). With the use of precise gene-editing tools such as CRISPR-Cas9, scientists can now target specific genes to enhance natural functions. For example, modifying promoter regions or removing inhibitory sequences allows *B. subtilis* to produce greater quantities of industrial enzymes, boosting efficiency in large-scale manufacturing processes. In the pharmaceutical sector, engineered strains are being utilized to synthesize stable recombinant proteins, including vaccines and therapeutic enzymes that address a variety of health conditions. In agriculture, genetically modified *B. subtilis* strains are being explored for roles such as improving nitrogen fixation, which could reduce reliance on chemical fertilizers and breaking down environmental pollutants like pesticides, contributing to eco-friendly farming. In medicine, altered strains could deliver targeted antimicrobials or combat drug-resistant pathogens using novel protective molecules. Biosafety measures, such as engineering strains to require specific nutrients for survival, help ensure containment and controlled use. The organism's natural ability to incorporate external DNA also facilitates rapid development and testing of new strains. Although regulatory challenges remain, the potential applications in biofuels, biodegradable.

Conclusion

Bacillus subtilis exemplifies how tiny organisms can influence our planet significantly. Starting from soil basics to leading in research and production, this germ shows adaptability and strength. We've looked at its core, making of enzymes and antimicrobials, fights with pathogens, and gene tweaking horizons. With ongoing studies, *B. subtilis* may transform areas from green cropping to advanced cures, reducing nature harm. Welcoming these helpful germs shows answers to big issues are often small-scale. Through fresh ideas, *B. subtilis* keeps going strong, and we could too.

References

Errington, J. and Wu, L. J. (2020). Microbe profile: Bacillus subtilis: Model organism for cellular development, physiology and ecology. *Microbiology*, 166(6): 514-516.

Gu, Y., Xu, X., Wu, Y., Liu, L., Li, M. and Chen, T. (2018). Advances and prospects of *Bacillus subtilis* cellular factories: From rational design to industrial applications. *Metabolic Engineering*, 50: 109-121.

Sumi, C. D., Yang, B. W., Yeo, I. C. and Hahm, Y. T. (2015). Antimicrobial peptides of the genus *Bacillus*: A new era for antibiotics. *Canadian Journal of Microbiology*, 61(2): 93-103.

Emasculation in Rice

P. Mariselvan, S. Subhashini and K. Chozhan

Abstract

Emasculation is a crucial technique in rice (*Oryza sativa* L.) hybridization programs that involves the removal of anthers from the flower to prevent self-pollination and ensure controlled cross-pollination. As rice is predominantly a self-pollinated crop, emasculation plays a significant role in transferring desired traits from one variety to another. Various emasculation methods such as hand emasculation, hot water treatment, and genetic male sterility are employed based on the breeding objectives, availability of resources, and the stage of flower development. This article highlights the importance of emasculation in rice improvement, discusses its methods, and emphasizes its contribution to the development of high-yielding hybrid varieties.

Introduction

Rice (*Oryza sativa* L.) is one of the most important cereal crops worldwide, serving as a staple food for more than half of the global population. To meet the growing food demand, plant breeders focus on developing high-yielding, stress-tolerant, and nutritionally superior varieties. Hybridization is a key breeding technique that allows the transfer of desirable traits from one variety (male parent) to another (female parent).Since rice is naturally self-pollinated, preventing self-fertilization in the female parent is essential this is achieved through emasculation.

Methods of Emasculation in Rice

Manual (Hand) Emasculation

- ✓ Widely used in breeding programs.
- ✓ The florets are selected one day before anthesis (flower opening).
- ✓ Lemmas and pale as are gently opened using forceps, and the six anthers are carefully removed.
- ✓ The emasculated florets are bagged to prevent unwanted pollination.

Hot Water Treatment

- ✓ Panicles are dipped in hot water at 40-44 °C for 5-10 minutes to kill or inactivate the anthers without harming the stigma.

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✓ Suitable for large-scale emasculation

Dragg's Technique (Clipping and Hot Water)

✓ The top portion of the spikelets is clipped.

✓ Treated with hot water to destroy pollen grains.

Genetic and Cytoplasmic Male Sterility (GMS and CMS)

✓ Use of male-sterile lines avoids the need for physical emasculation.

✓ Widely adopted in commercial hybrid rice seed production due to cost-effectiveness and uniformity.

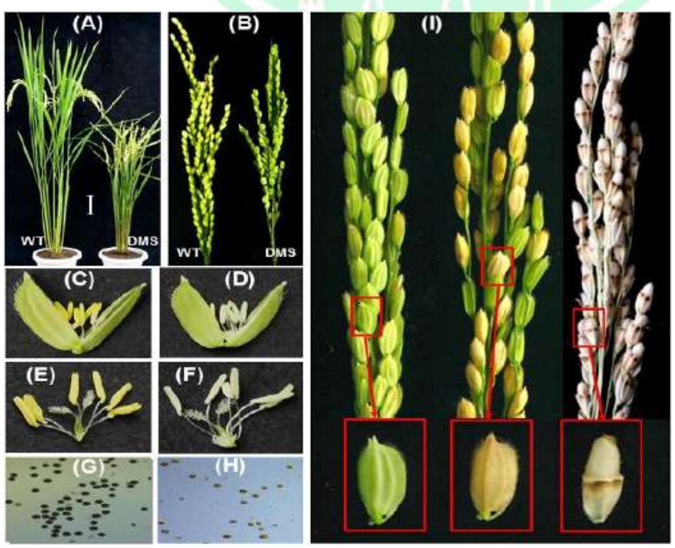
Significance of Emasculation in Rice Breeding

✓ Enables hybridization for heterosis breeding.

✓ Promotes genetic variability for developing improved varieties.

✓ Reduces risk of self-pollination, ensuring cross-breeding success.

✓ Integral to the success of hybrid rice technology, which boosts productivity by 15-20% over conventional varieties.



Conclusion

Emasculation is indispensable in rice hybridization programs. Continued refinement of techniques especially integrating biotechnological approaches and the exploitation of male-sterility systems will sustain and accelerate hybrid rice development, contributing to higher yields and global food security.

References

Virmani, S. S. (1994). Hybrid Rice Technology: New Developments and Future Prospects. International Rice Research Institute (IRRI).

Cheng, S. H., *et al*. (2007). Progress in research and development on hybrid rice: A super-domesticate in China. *Annals of Botany*, 100(5): 959-966.

Singh, R. K. and Singh, U. S. (2000). Hybrid Rice Breeding Manual. IRRI Publication.

Garlic having Great Strength Medicinal Value

Rajvaibhav Sul, Ashwini Benke and Poonam Shelke

Garlic has long been utilized in daily human life for its medicinal properties, and its therapeutic potential continues to attract scientific interest. Researchers across various disciplines are increasingly focused on exploring garlic's health benefits due to its wide range of biological effects and low toxicity. Garlic extracts have demonstrated antimicrobial activity against numerous strains of bacteria, fungi, and viruses, making it a valuable natural remedy. One of the key factors behind garlic's therapeutic power is its high concentration of sulfur-containing compounds, which are largely responsible for its health-promoting properties. Studies have also examined the role of garlic's bioactive components in the prevention and management of conditions such as cardiovascular disease, cancer, diabetes, high blood pressure, atherosclerosis, and hyperlipidemia. These findings have been widely acknowledged and praised in scientific literature.

Potentially Active Chemical Constituents of Garlic

Garlic is a nutritionally rich plant that contains at least 33 sulfur-based compounds, along with a variety of essential enzymes, minerals such as germanium, calcium, copper, iron, potassium, magnesium, selenium, and zinc, as well as vitamins A, B_1, and C. It also provides dietary fiber, water, and 17 amino acids, including lysine, histidine, arginine, aspartic acid, threonine, serine, glutamine, proline, glycine, alanine, cysteine, valine, methionine, isoleucine, leucine, tryptophan, and phenylalanine (Josling, 2005). Among the Allium species, garlic stands out for having the highest concentration of sulfur compounds, which contribute not only to its strong aroma but also to its many health-promoting effects. One of the most biologically active substances in garlic is allicin (also known as diallyl thiosulfinate), which is formed when garlic is chopped, minced, or crushed. This process disrupts S-allyl cysteine sulfoxide (alliin), allowing it to interact with the enzyme alliinase, rapidly converting it into allicin the compound responsible for garlic's distinct smell and many of its therapeutic benefits. Alliin is found in significant quantities, with concentrations ranging from 10 mg g^{-1} in fresh garlic to 30 mg g^{-1} in dried forms (Lawson, 1998). However, this conversion process is sensitive; the alliinase enzyme becomes inactive at a pH below 3.5 or when exposed to heat (Pedrazza-Chaverri *et al.*, 2006). Although allicin has long been considered the primary antioxidant and active compound in garlic, more recent research suggests that other components particularly polar phenolic and steroidal compounds may play an even more significant role. These compounds are odorless, heat-stable, and possess a

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wide range of pharmacological properties, making them valuable contributors to garlic's overall medicinal profile (Lanzotti, 2006).

Role of Garlic in Health

Garlic is widely recognized today as a powerful natural remedy with a wide range of health benefits. Its potent antibacterial and antifungal properties make it effective in combating various infections. Research has shown that garlic can help lower blood pressure, cholesterol, and blood sugar levels, while also preventing blood clots and supporting cardiovascular health. Moreover, it has anti-cancer potential and plays a role in strengthening the immune system, helping the body defend against illness and maintain overall wellness. One of garlic's lesser-known benefits is its ability to stimulate the lymphatic system, which aids in flushing out toxins and waste from the body. It also acts as a strong antioxidant, shielding cells from the harmful effects of free radicals. These protective effects may reduce the risk of chronic conditions such as cancer, heart disease, stroke, and certain viral infections. What makes garlic especially remarkable is its rich content of over 200 unique compounds, particularly sulfur-based ones, which enhance the body's natural defenses by activating health-promoting enzymes.

Reduces High Blood Pressure/Hypertension: Garlic has gained significant attention as a complementary treatment for managing blood pressure (Capraz *et al.*, 2006). Recent in vitro studies have supported this by revealing the vasoactive properties of garlic's sulfur compounds. Specifically, red blood cells have been shown to convert garlic-derived organic polysulfides into hydrogen sulfide, a naturally occurring molecule involved in vascular signaling and known for its cardioprotective effects (Benavides *et al.*, 2007). Clinical evidence also supports garlic's impact on blood pressure. One study reported that administering a 2400 mg garlic tablet containing 31.2 mg of allicin led to a notable reduction in diastolic blood pressure by 16 mmHg within five hours (McMahon and Vargas, 1993). Furthermore, a meta-analysis of data pooled from 415 patients found an average decrease of 7.7 mmHg in diastolic pressure, reinforcing garlic's potential as a natural antihypertensive agent (Silagy and Neil, 1994).

Prevents Diabetes: A number of animal studies support the effectiveness of garlic in reducing blood glucose in streptozotocin-induced as well as alloxan-induced diabetes mellitus in mice. Most of the studies showed that garlic can reduce blood glucose level in diabetic mice and rabbits (Ohaeri, 2001). A study was conducted to evaluate oral administration of garlic extract for 14 days on the level of serum glucose, total cholesterol, triglycerides, urea and uric acid, in normal and streptozotocin-induced diabetic mice. The result of the study showed significant decrease.

Anticancer: Of the many favorable actions of garlic, inhibition of the growth of cancer is perhaps the most prominent. It has several synergistic effects that either prevent or possibly may fight cancer.

The action of garlic has been attributed to stimulate immune effector cells including T-cell and natural killer cells. Numerous epidemiological, clinical and laboratory studies have demonstrated that, garlic has a great role in cancer prevention especially in relation to digestive tract cancers. Human population studies have shown that, regular intake of garlic reduces the risk of esophageal, stomach and colon cancer. This was thought to be due to the antioxidant effect of allicin in reducing the formation of carcinogenic compounds in the gastro intestinal tract (Galeone *et al.,* 2006). Dutch research in the Netherlands cohort study found a significant decrease in the development of stomach cancer in those consuming garlic close relatives of onions (Dorant *et al.,* 1996). Garlic reduces the risk of patients with prostate cancer, especially those with localized disease. Men in the higher of two intake categories of total Allium vegetables (>10.0 g day^{-1}) had a statistically significant lower risk of prostate cancer than those in the lowest category (between categories showed reductions in risk for men in the highest intake categories for garlic specifically. The reduced risk of prostate cancer was independent of body size, intake of other foods and total calorie intake and was more pronounced for men with localized prostate cancer than with advanced prostate cancer (Hsing *et al*., 2002). Prostate specific antigen serum markers had significant decreases during short term ingestion, but returned to baseline after 4 weeks (Mehraban *et al*., 2006). A very important epidemiological study for Americans has been published in which the intake of 127 foods (including 44 vegetables and fruits) was determined in 41,387 women (ages 55 to 69) followed by a five year monitoring of colon cancer incidence. The most striking result of this “Iowa Women’s Health Study” was the finding that garlic was the only food which showed a statistically significant association with decreased colon cancer risk. For cancers anywhere in the colon, the modest consumption of one or more servings of garlic (fresh or powdered) per week resulted in a 35% lower risk, while a 50% lower risk was found for cancer of the distal colon (Steinmetz *et al*., 1994).

Antiviral: Garlic and its sulfur constituents verified antiviral activity against coxsackievirus species, herpes simplex virus types 1 and 2, influenza B, para-influenza virus type 3, vaccinia virus, vesicular stomatitis virus, human immunodeficiency virus type 1 and human rhinovirus type 2. The order of compounds found in garlic for virucidal activity was, ajoene > allicin > allyl methyl thiosulfanate > methyl allyl thiosulfanate; no activity was found for the polar fractions, alliin, deoxyalliin, diallyl disulfide, or diallyl trisulfide. Several laboratory tests have shown that garlic is an effectual treatment for both the influenza B virus and herpes simplex virus. Two independent researchers in Japan and Romania have found that garlic is able to protect living organisms from the influenza virus (Tsai *et al.,* 1985). Most recently, a double blind placebo con trolled study has shown significant protection from the common cold virus. As conducted by The Garlic Centre, published in Advances in Therapy, this is the first serious work to show prevention, treatment and reduction of re infection benefits from taking Allimax Powder capsules once daily (Josling, 2001).

Antibacterial: Garlic extract inhibits the growth of Gram positive and Gram negative bacteria, such as Staphylococcus, Streptococcus, Micrococcus, Enterobacter, Escherichia, Klebsiella, Lactobacillus, Pseudomonas, Shigella, Salmonella, Proteus, and Helicobacter pylori (Tsao and Yin, 2001). Its antibacterial activity is mainly due to the presence of allicin produced by the enzymatic activity of allinase on alliin. Allicin is considered to be the most potent antibacterial agent in crushed garlic extracts, but it can be unstable, breaking down within 16 h at 23°C (Hahn, 1996). However, the use of a water-based extract of allicin stabilizes the allicin molecule due to the hydrogen bonding of water to the reactive oxygen atom in allicin or there may be water soluble components in crushed garlic that destabilize the molecule (Lawson, 1996). The disadvantage of this approach is that allicin can react with water to form diallyl disulphide, which does not exhibit the same level of antibacterial activity of allicin (Lawson and Wang, 1996).

Antifungal: Ajoene is an active compound found in garlic which plays a great role as topical antifungal agent (Ledezma and Apitz-Castro, 2006). Garlic has been shown to inhibit growth of fungal diseases as equally as the drug ketoconazole, when tested on the fungi *Malassezia furfur, Candida albicans*, Aspergillus, Cryptococcus and other Candida species (Shams-Ghahfarokhi *et al*., 2006).

A report from a Chinese medical journal delineates the use of intravenous garlic to treat a potentially fatal and rare fungal infection of the brain called *Cryptococcus meningitis*. In the report, the Chinese compared the effec tiveness of the garlic with standard medical treatment which involved a very toxic antibiotic called Amphotericin B. The study revealed that, intravenous garlic was more effective than the drug and was not toxic regardless of its dosage (Lemar *et al.,* 2007). A study found that Candida colonies were substantially reduced in mice that had been treated using liquid garlic extract. The study also revealed that garlic stimulated phagocytic activity. This implies that infections such as Candida may be controlled because garlic stimulates the body's own defenses. Garlic oil can be used to treat ring worm, skin parasites and warts if it is applied externally. Lesions that were caused by skin fungi in rabbits and guinea pigs were treated with external applications of garlic extract and began to heal after seven days (Sabitha *et al*., 2005).

Natural Farming: A Path to Sustainable Agriculture

Priya Satwadhar, Devshree Panchbhai and Bhavna Sharma

Introduction

Natural farming is a local low-input climate-resilient farming system that advocates the complete elimination of synthetic chemical agro-inputs. Instead, it encourages farmers to use low-cost, locally sourced inputs such as natural mixtures made using cow dung, cow urine, jaggery, pulse flour, mulch, crop covers, and symbiotic intercropping to stimulate the soil's microbial activities. It emphasizes the enhancement of soil conditions through improved organic matter and biological activity; crop diversification; enhanced biomass recycling with enriched biological interactions in the farm. Natural farming allows for a wide range of agro-ecological practices - composting, mulching, green manuring. A set of principle, guides the natural farming as: (i) the farm should be based on polycropping, where trees are integrated with various arable and perennial crops; (ii) No synthetic agro-inputs (fertilizers, pesticides, or herbicides) should be applied; (iii) soil should remain covered at all times and for the entire year using cover crops or mulch; (iv) local seeds, which are less costly and more resilient than hybrids, should be used; (v) bio-stimulants, should be used as a catalyst agent to enhance microbial activities of the soil, and botanical extracts for pest management; (vi) minimal tillage; and (vii) integration of livestock with crops for biological and economic synergies.

Features of Natural Farming

- ✓ According to natural farming principles, plants get 98% of their supply of nutrients from the air, water, and sunlight. And the remaining 2% can be fulfilled by good quality soil with plenty of friendly microorganisms as like in forests and natural systems
- ✓ The soil is always supposed to be covered with organic mulch during a maximum period of the year, which creates humus and encourages the growth of friendly microorganisms
- ✓ Farm made bio-cultures namely Beejamrit as seed treatment, Jeevamrit as foliar application and Ghanjeevamrit as soil application instead of any chemical fertilizer to improve the soil microflora. These bio-cultures are derived from very little cow dung and cow urine of desi cow breed which is the purest as far as the microbial

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content of cow dung and urine is considered.

- ✓ It holds the promise of enhancing farmers' income while delivering many other benefits, such as restoration of soil fertility and environmental health, and mitigating and/or reducing greenhouse gas emissions.
- ✓ In natural farming, neither chemical nor organic fertilizers are added to the soil. The decomposition of organic matter is encouraged by microbes and earthworms right on the soil surface itself, which gradually adds nutrition to the soil, over the period.
- ✓ Natural farming is just the way it would be in natural ecosystems as there is limited tilling of soil, no fertilizers, and no weeding done. Weeds are considered essential and used as a living or dead mulch layer.
- ✓ Natural, farm-made bio pesticides like Neem Astra are used to control pests and diseases
- ✓ Multi-cropping is encouraged over a single crop method

Importance of Natural Farming

There is an urgent need to increase 60-70% food production to feed the estimated 10 billion strong population of 2050. At present, the focus is not just on increasing crop yields, but also on being environmentally conscious in the process. Climate change is considered a major threat to agricultural production affecting the crops' productivity and environment. After the COVID pandemic, health matters a lot, and the consumers too are more aware of what they eat, going back to the old remedies and natural methods. Hence, today's focus is on providing comprehensive sustainable solutions to the humankind through complementary farming practice namely natural farming, which gains popular in agriculture.

The scope of natural farming extends far beyond just the fields, offering numerous advantages across various dimensions.

Environmental scope Soil health: Natural farming techniques improve the soil health through enhancing the organic matter in soil, promoting microbial activity and improving soil structure. Biodiversity: By avoiding monocultures and chemicals, natural farming supports a diverse range of flora and fauna, thus maintaining a diversified agro-ecosystem. Water conservation: With practices like mulching and no-till farming, there's a significant reduction in water evaporation, promoting efficient water use. Reduced pollution: Non-addition of synthetic chemicals in natural farming helps in maintaining the purity of water bodies including groundwater without pollution

Economic scope Cost efficiency: Natural farming often requires very fewer external inputs, thus reducing the production costs towards fertilizers, pesticides, other chemicals and machinery. Premium pricing: Produce cultivated through natural farming can often fetch higher prices in niche markets and among health-conscious consumers. Resilience: With diverse cropping and natural resilience building, natural farming can better handle market fluctuations and crop failures.

Health scope Nutrient rich produce: Crops grown in naturally nourished soil often possess a richer nutrient profile. Reduced chemical residues: The avoidance of synthetic chemicals means lesser residues on food, approaching towards safer consumption.

Social Scope Empowered communities: As natural farming leans on traditional knowledge, it empowers local communities and encourages collaborative efforts. Connection with nature: Natural farming promotes a deepened connection between farmers, consumers, and the earth, fostering respect for the environment.

Innovation and research scope new techniques: As the demand for natural farming grows, there is increasing research on refining techniques, discovering new practices, and integrating traditional knowledge with the modern science. Technological aids: Modern technologies of digital agriculture can be employed to support natural farming, right from apps that aid in pest identification to tools that help monitor soil/ crop health and quality.

Global scope Climate change mitigation: With its potential for carbon sequestration, natural farming can play a role in global efforts to combat climate change. Sustainable Development Goals: Natural farming aligns well with several United Nations Sustainable Development Goals, including good health and wellbeing, responsible consumption and production, climate action, life on land, and clean water and sanitation.

Conclusion

Natural farming is an agricultural revolution that will not only improve crop yields at minimum costs but will also help to increase farmers' incomes. With the pace at which soil degradation is happening globally, only 30 years of the harvest will remain for consumption. In order to save the world from a food crisis in the future, natural farming is considered to be an ideal solution. It is believed that the Government of India's long-term vision on sustainable agriculture with doubling the farmers' income could be achieved through the natural farming practice. Also, it is viewed that it is the right time to bring about this transition from chemical 10 farming to natural farming by creation of vast awareness among the farming community through several schemes and capacity building programmes.

Single Seed Descent Method

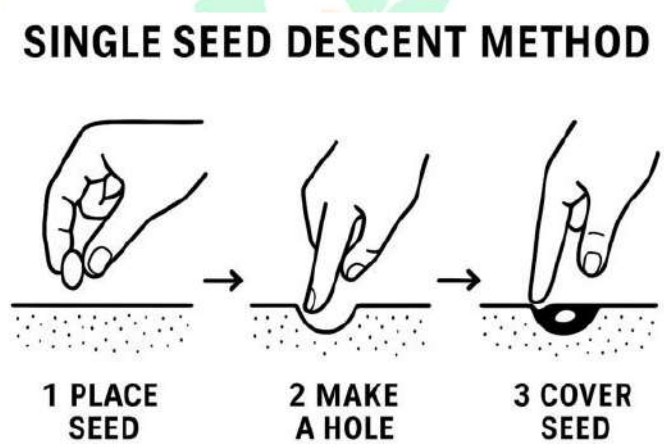
Nithiya Sri Sankar, S. Subhashini and K. Chozhan

Abstract

The Single Seed Descent (SSD) method is a rapid and efficient breeding technique used to advance generations of self-pollinated crops. It is particularly valuable for handling large populations and reducing the time required to achieve homozygosity. In this method, a single seed is harvested from each plant in segregating generations (F_2, F_3, etc.) and advanced without selection until later generations. The main advantage of SSD is that it ensures a random sample of the genetic diversity present in the base population is preserved while quickly reaching homozygous lines. This method is widely used in cereal and legume crop breeding programs due to its simplicity, cost-effectiveness, and ability to develop stable lines for further selection and evaluation.

Introduction

Single-seed-descent (SSD) is a modification of conventional plant breeding used by breeders to rapidly fix genes in breeding lines. As its name implies, SSD is the advancement of one randomly selected seed per plant through the early segregating stages (Goulden, 1939; Brim, 1966). As only one seed is needed to produce the next generation, plants can be grown under conditions that accelerate flowering and seed-set, but do not encourage high yield. This leads to faster generation turnover by reducing the length of the generation cycle, enabling multiple generations per year. This method is also known as the modified pedigree method (Brim, 1966). Goulden (1939) suggested that the segregating generations derived from hybridization could be rapidly advanced in the greenhouse with no selection and taking only one or two progenies from each plant in each successive generation.



Large numbers of near-homozygous lines can then be tested in the field only for a short time after the initial hybridization. This is a rapid method of inbreeding to obtain sufficient homozygosity in few years before resorting to single plant selection.

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Current SSD methodologies enable a maximum of three generations per year to be developed in most grain legume breeding programs.

Principles of single seed descent method

The SSD method is based on advancing generations by using one seed per plant regardless of phenotype. It avoids early selection, allowing genetic variability to be maintained until later generations (F_5-F_6) when most loci reach homozygosity.

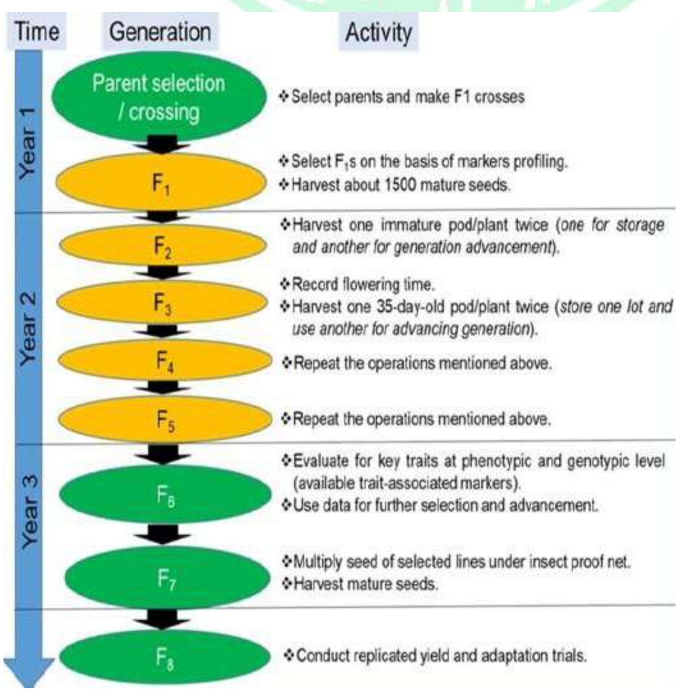
Procedure

Initial Cross: Make a cross between two parent plants to create an F_1 generation.

F_1 to F_2: Grow the F_1 plants and allow them to self-pollinate or intermate to produce F_2 seeds.

Single Seed Selection: From each F_2 plant, select a single seed randomly, regardless of phenotype.

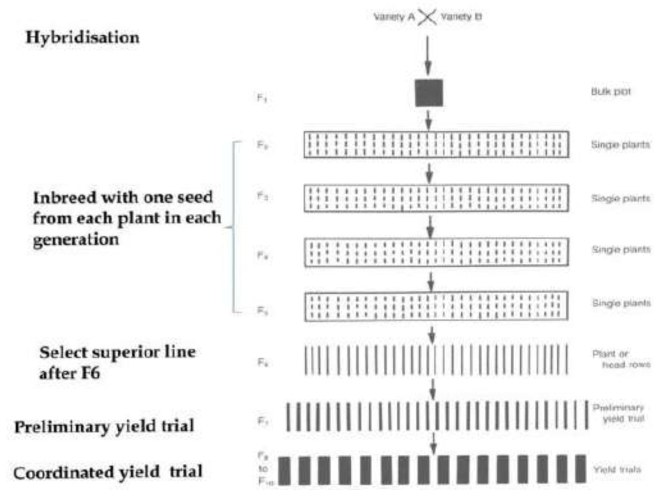
Advance Generations: Grow the selected seeds, and repeat the process of single selection for each subsequent generation (F_3, F_4, F_5, etc.) until the desired level of homozygosity is achieved.



Selection and Evaluation: Once the desired level of homozygosity is reached (usually F_5 or F_6), evaluate the lines for desirable traits and select superior lines for further testing and potential release as new varieties.

Applications

The Single Seed Descent (SSD) method has several applications in plant breeding:



Rapid Generation Advancement: SSD accelerates the breeding process by quickly advancing generations, saving time and resources.

Inbreeding: It helps achieve homozygosity in self-pollinating crops, making it easier to fix desirable traits.

Quantitative Trait Improvement: SSD is effective for improving complex traits like yield, disease resistance, and drought tolerance.

Genetic Diversity: It maintains genetic diversity in breeding populations, allowing for a broader range of traits to be expressed and selected.

Line Development: SSD is used to develop pure lines for use in hybrid breeding programs or for release as new varieties.

The SSD method is particularly useful for breeding self-pollinating crops like wheat, rice, soybeans, and barley.

Advantages

- ✓ Rapid homozygosity compared to pedigree method.
- ✓ Less labour and cost, since selection is delayed.
- ✓ Maintains broad genetic variability.
- ✓ Suitable for greenhouse or off-season nurseries to shorten breeding cycles.

Limitations

- ✓ No selection in early generations, so undesirable traits may persist.
- ✓ Useful mainly in self-pollinated crops, less effective in cross-pollinated species.
- ✓ Some genetic variation may be lost due to random single seed sampling.

Conclusion

The Single Seed Descent method is an efficient and practical approach for advancing segregating generations in plant breeding. It allows breeders to conserve genetic variability while quickly achieving homozygosity, thus saving time and resources. Although it has limitations such as the absence of early selection, its effectiveness in crops like wheat, soybean, rice, and barley has made it a widely used breeding strategy. When combined with modern molecular tools, SSD continues to be a powerful method for crop improvement.

References

Allard, R. W. (1999). Principles of Plant Breeding (2^{nd} ed.). Wiley.

Fehr, W. R. (1987). Principles of Cultivar Development: Theory and Technique. Macmillan Publishing Company.

Singh, B. D. and Singh, A. K. (2021). Plant Breeding: Principles and Methods (11^{th} ed.). Kalyani Publishers.

Sharma, J. R. (1994). Principles and Practice of Plant Breeding. Tata McGraw-Hill.

Community Forestry System: An Approach practiced by Garo tribe in Conservation of Forest Aid for Rural Livelihood Sustainability

Tarun Kumar Das, Sanjay Chetry, Sagarika Borah, Monica Suresh Singh and Naorem Arunkumar Singh

Introduction

The Garo Hills region of Meghalaya encompasses a diverse landscape of forests spread across plains and hilly terrain. A significant portion of the forests is managed under community forestry systems, locally referred to as "reserved" forests by the indigenous Garo (one of the tribes of Meghalaya) communities. This practice, rooted in ancestral traditions, continues to thrive through active collaboration between the forest department, local settlers and the Garo tribes**.** Forest conservation increasingly strives for win-wins, trying to protect nature as well as support human well-being (McKinnon *et al*., 2016). Most of the land property of the forest is used as participatory community forestry which is locally called reserved by the *Garos*. This system was practicing from their ancestor and still it is going on successfully. Local forest department, settlers and the *Garo* tribe are the key component under the forestry. This community-based forest management system serves as a vital bridge between environment and development, engagement of local communities and devolved control over natural resources. A community approach to forest management organized at a grass grassroots level by community-based institutions which has been implemented in India since 1970s and is considered, by and large, to be successful and anideal forest management model in the present world forestry scenario (Balooni, 2002). Such comparable vision, rooted in indigenization was upheld for generations by Garo tribe, residing at the Garo Hills region of Meghalaya through an innovative community driven approach that integrates forest conservation with rural livelihood sustainability (Das *et al.*, 2016). This region encompasses a diverse landscape of forests spread across plains and hilly terrain, harbors diverse forest ecosystems. A significant portion of the forests is managed under community forestry systems. This practice, deeply entrenched in ancestral traditions, illustrates a harmonious synergy between tradition and modern forest management practices.

Community Forestry System (CFS) of Garo Hills

The CFS of Garo Hills region particularly Marapara, Sananggre, Rongbokgre and Kamagre villages, operates on a silvicultural model, where trees and bamboo serve as the principal components. Prominent tree and fruit species include Teak, Agor, Sal, Neem, Mango, Jackfruit, Cashew Nut, Sisu and

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other wild species, alongside medicinal and horticultural plants that contribute to economic and environmental benefits. Participants of the community forestry system are granted rights to intermediate forest products such as branches, pruned material and deadwood, while the proceeds from larger harvests are managed collectively. In periods of resource scarcity, harvesting is suspended for 4-5 years to allow regeneration, demonstrating a strong commitment to sustainability. Community forestry system has empowered marginalized groups, particularly the landless, small farmers and adjacent households, by providing them with access to forest resources and income opportunities. Land under the jurisdiction of village headmen (Nokmas) serves as the base for these projects, fostering a participatory approach that integrates traditional knowledge with contemporary conservation methods Despite challenges, this model has emerged as a viable strategy for addressing deforestation, improving biodiversity and generating additional livelihood opportunities. It emphasizes community involvement in creating and maintaining forests on government or panchayat wastelands, ensuring environmental sustainability and socio-economic upliftment. The forest department also plays a pivotal role by providing technical support and training to villagers, further strengthening the system.

Critical importance of CFS of Garo Hills

Community forestry system of Garo Hills serves as a viable and sustainable approach in conserving and utilizing the indigenous resources while ensuring ecological balance and community livelihood security. Therefore, expanding its implementation could significantly contribute to forest conservation and rural livelihood security, as well as serving as a replicable model for similar landscapes across the North Eastern region and beyond. Importantly, this system acts as a buffer against the adverse impacts of climate change, which has disrupted agricultural production through erratic rainfall, flash floods, and rising temperatures. During periods of crop failure or lean agricultural seasons, villagers depend on the continuous supply of resources from this forestry system to sustain their livelihoods. Additionally, it also sustains the communities during the period of vulnerability and socio-economic stress, such as those experienced during the COVID-19 pandemic. By bridging these gaps, community forestry not only supports rural communities during crises but also advances sustainable development goals in tribal regions like West Garo Hills. Its expansion holds immense potential for promoting forest conservation and ensuring rural livelihood security across broader landscapes.

Socio economic and environmental benefits of CFS of Garo Hills

Community forestry represents a collaborative approach to forest management in which, the local communities are entrusted to protect, restore and sustainably use all the forest resources, ensuring ecological integrity with genuine socio-economic advancement. Across the globe, various case studies of this system from watershed restoration in Nepal to timber-certified ejidos inn Mexico and agroforestry cooperatives in Latin America illustrates how such system cand turn historically marginalized and forest-dependent populations into active stewards and beneficiaries of their natural environment. Through collective rights and participatory governance, communities can establish stable and diversified incomes through timber, non-timber forest products, eco-tourism and value-added forest enterprises. These successes have been equally realized in job generation that attracts youth into rural areas, lowering pressure on urban migration, ensuring inclusion of decision-making through women and indigenous groups and in the promotion of social cohesion and resilience at the local level. On the environmental side, community forestry contributes to the reduction of deforestation and forest degradation by intervening with sustainable harvesting, restoration of degraded lands and enhancement of biodiversity, while good forest governance safeguards watershed, controls soil erosion and climate-related disasters. Ecological restoration in adapting global warming must increase the carbon sequestration level, thus preserving essential ecosystem services like air and water. An example of communities reviving barren lands through creation of bio-briquettes in Nepal or planting trees on a large scale in the UK to improve soil health is afforded by way of environmental as well as livelihood benefits. However, challenges such as unclear land tenure, market access barriers, and conflicted interests remain, but experiences from successful models across Europe, the Americas, Africa and Asia indicate that capacity building, enabling policies and strong institutional foundations at the local level are indispensable to maintaining the economic viability and environmental appropriateness of community forestry systems. Inherently, community forestry serves as evidence as in the community forestry system of Garo Hills, that when communities are empowered to manage forest lands and local ecological services, they stays protected, offering a scalable model for intertwining human and environmental prosperity across the globe.

Key Insights of CSF of Garo Hills and Replication Model

The CSF of Garo Hills works on a silvicultural model, where trees and bamboo serve as the principal components. Additionally, prominent trees like Teak, Agor, Sal, Neem, Mango, Jackfruit, Cashew Nut, Sisu, and wild species, alongside medicinal and horticultural plants contribute to economic and environmental benefits. Such community forestry meets the local biomass needs, promote *in situ* biodiversity, conserve soil and water, carbon sequestration and provide grass for livestock (Pandy *et al.*, 2016). Furthermore, the participants are granted rights to intermediate forest products such as branches, pruned material, and deadwood, while the proceeds from larger harvests are managed collectively. A Village Forest Management Committee (VFMC) oversees the regulation, utilization, and maintenance of these forests, ensuring equitable benefits and sustainable practices. The VFMC enforces rules and levies fines for non-compliance, employs security personnel for forest protection, and determines the timing and extent of harvests based on forest health. In periods of resource scarcity, harvesting is suspended for 4-5 years to allow regeneration, demonstrating a strong commitment to sustainability. Community forestry has empowered marginalized groups, particularly the landless, small farmers, and adjacent households, by providing them with access to forest resources and income opportunities (Dev *et al.*, 2003). Land under the jurisdiction of village headmen (Nokmas) serves as the base for these projects, fostering a participatory approach that integrates traditional knowledge with contemporary conservation methods (Das *et al.*, 2016). The villagers also collect the bee colonies for domestication from the reserve forest area during spring season and harvest wild mushroom during rainy season. Despite challenges, this model has emerged as a viable strategy for addressing deforestation, improving biodiversity, and generating additional livelihood opportunities (Das, 2012). Its expansion holds immense potential for promoting forest conservation and ensuring rural livelihood security across broader landscapes. The success of CFS of Garo Hills serves as a template of knowledge that can be replicated in other regions by having similar socio-ecological contexts. For effective replication, it is important that local governance mechanisms, such as Village Forest Management Committees (VFMC), be strong, inclusive of the poor and equitable in benefit distribution. To improve the adaptive capacity and resilience status of the community forest management, it is always better to blend traditional ways with scientific and technical supports. Additionally, capacity-building, participatory planning and helping marginalized groups to actively take part in forest management should constitute replication efforts.

Fig: Community Forestry System of Garo Hills, Meghalaya

Conclusion

Continuous deforestation and forest degradation have long been concerns of Indian policy makers. Community forestry system of Garo Hills region sets up a sustainable model led by the community, putting together traditional knowledge and equitable resource sharing while enforcing sustainability practices. This model enhances rural livelihoods, conserves biodiversity, and strengthens climate resilience especially during lean and dry agriculture period. Given its established socio-economic and environmental advantages, it presents a promising model that can be replicated in North East India and elsewhere, thereby aiding in the achievement of Sustainable Development Goals (SDGs) particularly SDG 1 - No Poverty, SDG 13 - Climate Action and SDG 15-Life on Land. Ongoing institutional backing could enhance its influence on sustainable development and the preservation of forests.

References

McKinnon, M. C., Cheng, S. H., Dupre, S., Edmond, J., Garside, R., Glew, L., ... and Woodhouse, E. (2016). What are the effects of nature conservation on human well-being? A systematic map of empirical evidence from developing countries. *Environmental Evidence*, 5(1): 1-25.

Das, T., Samajdar, T., Islam M., Singh N. A. and Marak, G. (2016). Traditional Farming System: A Case Study of Garo Tribe in West Garo Hills District of Meghalaya, North-Eastern India. *International Journal of Agriculture Sciences*, ISSN, 0975-3710.

Pandey, S. S., Cockfield, G. and Maraseni, T. N. (2016). Assessing the roles of community forestry in climate change mitigation and adaptation: A case study from Nepal. *Forest Ecology and Management*, 360: 400-407.

Gilmour, D. (2016). Forty years of community-based forestry: A review of its extent and effectiveness.

Dev, O. P., Yadav, N. P., Baginski, O. S. and Soussan, J. (2003). Impacts of community forestry on livelihoods in the middle hills of Nepal. *Journal of forest and Livelihood*, 3(1): 67-77.

Das, N. (2012). Impact of Participatory Forestry Program on Sustainable Rural Livelihoods: Lessons from an Indian Province. *Applied Economic Perspectives and Policy*, 34: 428-453.

Strategic Water Footprint Management for Sustainable and High Efficiency Crop Production

Yashaswini R., Prem Sagar S. P., Raghavendra V. C., Sridhara M. R. and Sanjay M.

Introduction

Water is essential for sustaining all forms of life, food production, economic development and for general well-being. It is impossible to substitute for its uses, difficult to de-pollute, expensive to transport and it is truly a unique gift to mankind from nature. So it is necessity to use water efficiently and conserve for future generation. India's agriculture sector accounts for about 16% of the nation's total greenhouse gas (GHG) emissions, amounting to approximately 417.22 million tons of CO_2 equivalent annually, with methane (CH_4) contributing 74% and nitrous oxide (N_2O) 26%. Over the past five decades, agricultural GHG emissions in carbon equivalents have increased by around 161%, largely driven by intensive input- and energy-dependent practices such as high nitrogen fertilizer application and extensive use of farm machinery. Cereals dominate India's food grain production at 93.5%, with rice, wheat and maize making up 87.2% of the total. The concept of a carbon footprint (CF), expressed in CO_2 equivalents, is widely applied to quantify emissions associated with production and consumption cycles. Assessing CFs for key crops like rice, wheat and maize is crucial for devising strategies to curb agricultural emissions. Such evaluations, which consider all input-related emissions per production cycle, have been instrumental in identifying low-carbon solutions across sectors including bioenergy, industry, households and crop production. These studies inform policy design and support climate change mitigation efforts, promoting transitions toward a low-carbon agricultural economy.

Ecological footprints: It is a resource and emission accounting tool designed to track human demand on the biosphere's regenerative capacity.

Indicators of ecological footprints

Water footprint, carbon footprint, energy footprint, biodiversity footprint, phosphorus foot-print, nitrogen footprint and chemical footprint.

Carbon footprint: The total amount of greenhouse gases produced directly and indirectly to support human activities, usually expressed in equivalent tons of carbon dioxide (CO_2).

Energy foot print: It is a measure of land required to absorb the CO_2 emissions.

Nitrogen footprint: The total amount of nitrogen released to the environment as a result of an entity's

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consumption patterns.

Water footprints

Measure of Indicator of human appropriation of fresh water in terms of volume of water consumed or polluted, expressed in cubic meters per unit time. It helps understand how much water is required to produce product. To enhance environmental integrity and increase sustainable performance. Water footprint of humanity has exceeded sustainable levels and is unequally distributed among the people so it helps to minimize water footprint of humanity. To understand and address the challenges of global water stress.

Applications of water footprints

- ✓ The concept of water footprint has introduced as a new and wider dimension in integrated water resources management.
- ✓ The analysis of water footprint trade is providing new perspectives in global water policy and sustainable management of water resources.
- ✓ Water footprint can provide complementary roles in the context of integrated water resources management.
- ✓ Water footprint data raises awareness among the general public, government and stakeholders considering the environmental impact of social activities.

Components of water footprint

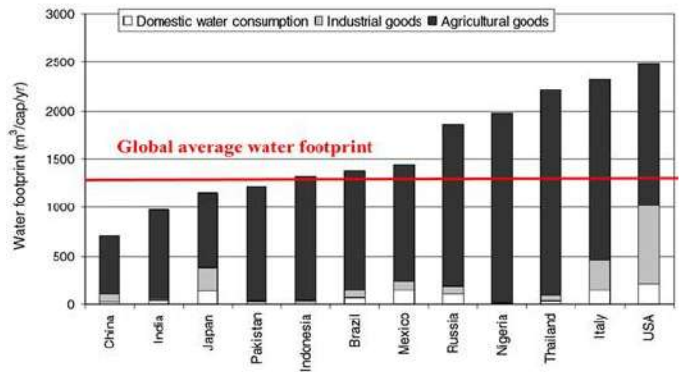


Figure 1: The national water footprint per capita and the contribution of different consumption categories for some selected countries

Water footprint of national consumption

Total amount of water that is used to produce the goods and services consumed by the inhabitants of the nation. Two components:

- ✓ Internal water footprint → inside the country.
- ✓ External water footprint → in other countries.

Water footprint of national consumption = Internal water footprint + External water footprint

Water footprint calculation

- ✓ http://waterfootprint.org/en/resources/interactive tools/personal-water-footprint-calculator/
- ✓ http://waterfootprint.org/en/resources/interactive tools/personal-water-footprint-calculator/ personal-calculator-extended/

Water footprint (WF) of major crops

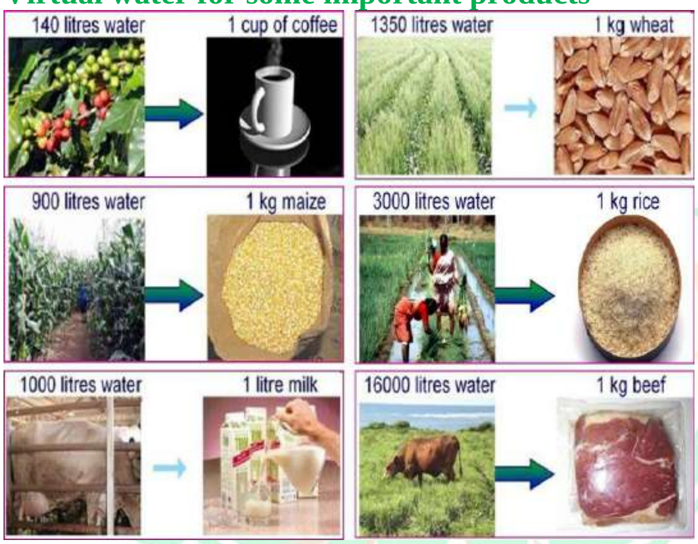
Crops	Global WF ($m^3\ t^{-1}$)	Components of water footprints (%)		
		Green	Blue	Grey
Rice	1325	48	44	08
Wheat	1830	70	19	11
Maize	1067	53	24	23
Cotton	256 ($Gm^3\ year^{-1}$)	42	39	19

Green water footprint reduction

The green water footprint in agriculture can be reduced by implementing various farming techniques and practices such as:

- ✓ Mulching and conservation tillage, thereby reducing evaporation from the soil surface.
- ✓ Mixed cultivation and intercropping, offering a variety of land cover, thereby reducing evaporative losses. This also improves biodiversity (reducing the risk of singular pests whose numbers would remain unchecked in a mono-crop).
- ✓ Good forecasting of the monsoon rains.

Virtual water for some important products



Blue water footprint reduction

- ✓ Increasing blue water availability by making use of rainwater harvesting.
- ✓ Rainwater harvesting captures water during the wet season and, when used during the dry season, reduces pressure on scarce surface and ground-water resources.
- ✓ Strategically timed irrigation during dry spells along with good pest and soil management leads to increased efficiency (through improved productivity).
- ✓ Improved weather forecasting to guide irrigation scheduling to meet the plant's water needs increases irrigation effectiveness.
- ✓ Interlinking of rivers program.

Gray water footprint reduction

- ✓ Can be achieved through organic farming.
- ✓ Nutrient management and through substituting chemicals that have a lower toxicity, thereby generating a smaller grey water footprint.
- ✓ Pesticides that have a low water footprint should be used.
- ✓ Fertilizers should only be applied in amounts in line with plant and soil requirements to supplement any deficit in order to optimize productivity and reduce runoff or leaching into fresh water.
- ✓ Soil testing is required to accurately apply nutrients; farmers need to learn the benefits of investing in soil testing.
- ✓ Recycling of waste water from agriculture and industries.

Conclusion

Water footprint helps to understand how much water is required to produce product and address the challenges of global water stress. Water footprint reduction in irrigated crop production is the way forward for efficient and sustainable water resource use. Reduction in consumptive WF of a crop at field level can be achieved by changing management practice such as irrigation technique, irrigation strategy and mulching practice.

References

Hoekstra, A. Y. (2017). Water footprint assessment: evolvement of a new research field. *Water*

Resources Management, 31(10): 3061-3081.

Wiedmann, T. and Minx, J. (2008). A definition of 'carbon footprint'. *Ecological Economics Research Trends*, 1: 1-11.

THE Agriculture MAGAZINE

Nanotechnology: Role in Agriculture with Reference to Crop Improvement

Netram, Anushka Kuntal and Mamta Tanwar

Abstract

Nanotechnology has emerged as a powerful tool in modern agriculture, offering innovative solutions to overcome challenges such as declining soil fertility, nutrient inefficiency and biotic and abiotic stresses. It enables precise management of agricultural inputs, enhances crop productivity and contributes to sustainable farming. The use of nanoparticles in agriculture has expanded into various applications such as genetic improvement, targeted delivery of fertilizers and pesticides, rapid disease diagnostics and environmental monitoring. Nanomaterials like carbon nanotubes, gold nanoparticles, mesoporous silica nanoparticles and quantum dots are being explored for enhancing efficiency and precision in crop management. Despite the immense potential, issues like toxicity, cost and environmental safety must be addressed for its responsible application. This article highlights the principles, types, applications, advantages and limitations of nanotechnology in agriculture with reference to crop improvement.

Introduction

India is Agriculture dependent country with more than 60% of the population reliant on it for their livelihood. In this era of climate change and increasing population, Agricultural scientists and Farmers are facing a wide spectrum of challenges such as stagnation in crop yields, low nutrient use efficiency, declining soil organic matter, multi-nutrient deficiencies, biotic and abiotic stress, shrinking arable land and water, high food demand etc. We need to attain a sustainable growth in agriculture at the rate of 4% to meet the food security challenges and hence, in addition to the conventional breeding methods new advance techniques like biotechnology and nanotechnology are being exploited.

What is Nanotechnology … ?

The term "Nanotechnology" coined in 1974 by Norio Taniguchi at the University of Tokyo. Nanotechnology is the manipulation of individual atoms, molecules or molecular clusters into structures to create materials with new properties. It is now more properly labeled as "molecular nanotechnology" (MNT) or "nano-scale engine-ering". The word "nano" comes from the Greek for "dwarf". A nanometre is one-billionth of a metre i.e.

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10^{-9}. Human hair is 80,000 nm wide.

Limitation of current technologies: High cost and short shelve half-life of some reagents such as enzymes and DNA primers, limit the application of most conventional pathogen detection techniques in developing nations. ELISA and PCR, require extensive sample preparation and have long readout times, which delay prompt response and disease containment.

The potential of nanotechnology: Due to unique electrical, magnetic and catalytic properties of nanomaterials. Faster, sensitive and more economy-ical diagnostic assays can be developed. Without any sample preparation, providing fast and reliable results in simple and user- friendly formats.

How nanotechnology evolved…?

Richard Smalley: US Senate passed a resolution to honour Smalley, crediting him as the "Father of Nanotechnology." Won the 1996 Nobel Prize for discovering a new form of carbon molecule of sixty carbon atoms (C60). Also called 'buckyball'. Today C-60 has become one of a growing number of building blocks for a new class of nano-sized materials. Nanotech began to accelerate in the late 1990's.

What is unique about nanotechnology?

Small size (High surface to volume ratio), therefore requires self-assemblers significantly higher hardness, breaking strength and toughness at low temperatures and super plasticity at high temperatures. Additional electronic states, high chemical selectivity of surface sites and significantly increased surface energy. New entryways (high mobility in human body, plants and environment).

Characteristics of nanoparticles

- ✓ Small size (1-1000 nm)
- ✓ Large surface to volume ratio
- ✓ High activities
- ✓ Change in the physical and chemical properties with respect to size and shape

Nanoparticles are generated naturally by erosion, fires, volcanoes and marine wave action. Nanoparticles are also produced by human activities such as coal combustion, vehicle exhaust and weathering rubber tires.

Engineered NPs (ENPs): Nanomaterials that are intentionally produced and designed with specific properties related to their shape, size, surface properties and chemistry.

Types of Nanoparticles or Engineered NPs

Carbon nanotubes (CNTs): Allotropes of carbon that have a cylindrical nanostructure with diameters ranging from <1 nm to 50 nm. They are categorized as either single-walled nanotubes (SWNTs) or multi-walled nanotubes (MWNTs). CNT used to deliver desired molecules into the seeds during germination so as to protect them from the diseases.

Magnetic NPs: NPs that contain magnetic materials of elements such as Fe, Ni, Co and their chemical compounds and used for targeted delivery using magnetic field gradients.

Mesoporous silica NPs (MSNs): NPs that comprises of a honeycomb like porous structure with pore size and outer particle diameter in the nano-meter range. This type of NP has hundreds of empty channels that are capable of encapsulating or absorbing large amounts of agrochemicals or bioactive molecules.

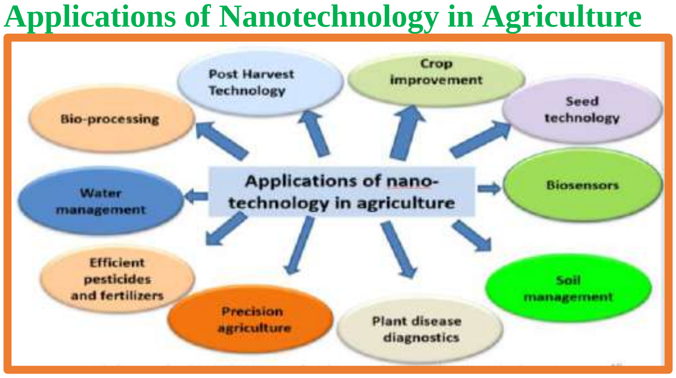
Quantum dots (QDs): Tiny particles or Nano crystals of a semiconductor material with diameters ranging from 2 to 10 nm. This type of NP can produce a distinctive fluorescence that can be used for sub-cellular labelling and imaging.

Gold Nanoparticles: Type of metallic nanoparticle of size <50 nm prepared with different geometries, such as Nano spheres, nanoshells, nanorods or nanocages. These are excellent labels for biosensors Quantum Dots Gold Nanoparticles.

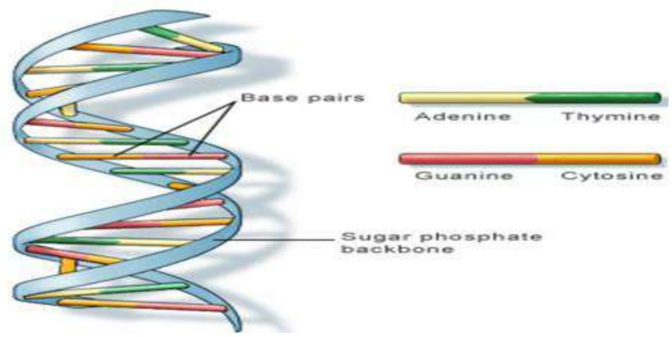
Various Microbes in the Synthesis of NPs

Microorganism	Nanoparticle	References
Fusarium oxysporum	Ag	Duran *et al*. (2005)
Aspergillus niger	Zn, Ag	Jaidev and Narasimha (2010)
Aspergillus fumigatus	Zn	Tarafdar *et al.*, (2013)
Alternaria alternata	Se	Sarkar *et al*. (2011b)
Trichoderma asperellum	Ag, Au, Zn	Mukherjee *et al*. (2008)
Bipolaris nodulosa	Au, Ag	Saha *et al*. (2010)
Rhodococcus species	Mn, Ag	Ahmad *et al*. (2003)
Neurospora crassa	Au, Ag	Castro-Longoria *et al.* (2011)
Penicillium sp.	Au	Du *et al*. (2011)
Proteus mirabilis	Zn, Au	Samadi *et al*. (2009)
Trichoderma harzianum	Ag	Singh and Balaji (2011)

Applications of Nanotechnology in Agriculture



DNA in Nano World: The DNA molecule has appealing features for use in nanotechnology:



Its minuscule size, with a diameter of about 2 nanometers, its short structural repeat (helical pitch) of about 3.4-3.6 nm, its 'stiffness', with a persistence length (a measure of stiffness) of round 50 nm.

Atomically Modified Seeds: In March 2004, ETC Group reported on a nanotech research initiative in Thailand that aims to atomically modify the characteristics of local rice varieties. Researchers "drilled" a hole through the membrane of a rice cell in order to insert a nitrogen atom that would stimulate the rearrangement of the rice's DNA. So far, researchers have been able to alter the colour of a local rice variety from purple to green.

Nano pore Technology (Solid State): The bimolecular Nano pore detection technology to rapidly discriminate between nearly identical strands of DNA. Single molecule of DNA is drawn through 1-2 nm in size pores that serve as a sensitive detector. This technology has the potential to detect DNA polyploidy and DNA mutations.

Potential Applications of Nanotechnology in Genetics

- ✓ High throughput DNA sequencing and nano-fabricated gel-free systems

- ✓ Nanoparticles For Gene Delivery
- ✓ Microarrays and expression profiling
- ✓ Increasing the speed and power of disease diagnostics
- ✓ Creating bio-nanostructures for getting functional molecules into cells
- ✓ Miniaturizing biosensors
- ✓ Controlled gene delivery
- ✓ Multiple gene delivery
- ✓ Study of gene function

High-throughput DNA sequencing and nano-fabricated gel-free systems: Research in nanotechnology is advancing toward the ability to sequence DNA in nanofabricated gel-free systems, which would allow for significantly more rapid DNA sequencing. Coupled with powerful approaches such as association genetic analysis, DNA sequencing data of the crop germplasm, including the cultivated crop gene pool and the wild relatives can potentially provide highly useful information about molecular markers associated with agronomically and economically important traits. Thus, nanotechnology can enhance the pace of progress in molecular marker-assisted breeding for crop improvement.

Hormone and Antibiotics Delivery in plants: Controlled release involves the combination of a biocompatible material or device with a drug to be delivered in a way that it can be delivered and released at diseased sites in a designed manner. Nanomaterials such as mesoporous silica particles (MSNs), AuNPs, carbon nanotubes (CNTs), and layer double hydroxides (LDHs), have emerged as promising vectors for the delivery of genome engineering tools (DNA, RNA and proteins) and antibiotics to plants in a species-independent manner with high efficiency.

Microarrays and Expression Profiling: Micro-array-based hybridization methods allow to simultaneously measure the expression level for thousands of genes. The less expensive procedure having similar sensitivity and specificity is DNA and protein functional nanoparticles (FNP) They may be used as hybridization probes in single nucleotide polymorphism (SNP) screening and to detect biological markers. The development of novel formats for sequence determination and patterns of genomic expression which can have significantly higher throughput than current technologies is vital.

Nanopore sequencing: Nanopore sequencing is used to determine the sequence of DNA/RNA bases. Nanopore-based DNA sequencing protocols allowing single molecule, electrical detection of DNA sequence and have the potential of low sample preparation work, high speed, and low cost.

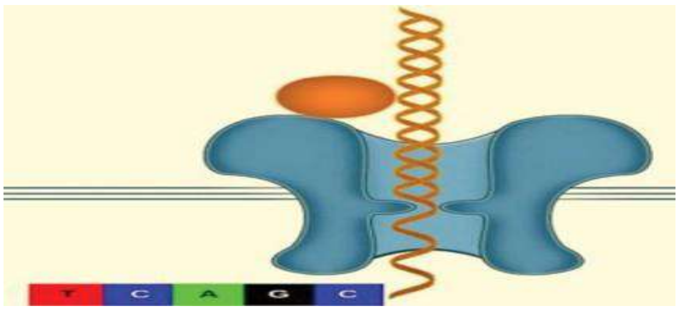
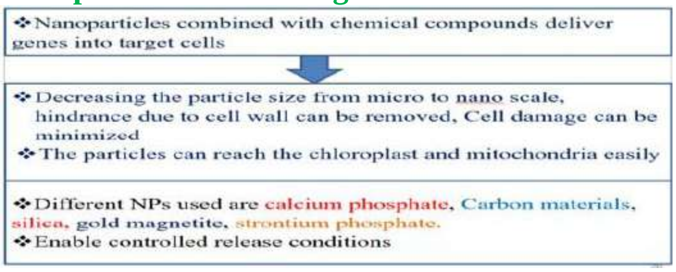


Fig.: Diagram of a DNA molecule travelling through a protein nanopore

These advances are a substantial step forward in improving this inexpensive and potentially more rapid alternative to next-generation sequencing.

Nanoparticles mediated genetic transformation



Advantages of Nanoparticles

- ✓ Enhanced Crop Productivity
- ✓ Efficient Use of Inputs
- ✓ Improved Disease Detection and Management
- ✓ Genetic Improvement of Crops
- ✓ Sustainable Agriculture
- ✓ Improved Post-Harvest Management
- ✓ Rapid and Sensitive Diagnostics

Disadvantages of Nanoparticles

- ✓ Risk of toxic materials entering the food chain.
- ✓ Cost benefit ratio is high.
- ✓ Difficulty in synthesis, isolation and application.
- ✓ Environmental degradation.

Conclusion

Nanotechnology represents a revolutionary step forward in agricultural science, offering advanced tools for improving crop productivity, disease detection, and resource efficiency. By enabling precision agriculture, targeted delivery systems, and rapid genetic analysis, nanotechnology holds the potential to transform the future of food production. However, careful regulation, environmental monitoring, and cost management are essential to ensure that this powerful technology contributes safely and sustainably to global agriculture.

Nano Fertilizers: Game Changer or Supplement?

Amit Arun Baikar

Abstract

The growing global population, declining arable land, and environmental pressures pose significant challenges to modern agriculture. Conventional fertilizers, though vital for crop productivity, often result in nutrient losses, soil degradation, and environmental pollution. Nano fertilizers, developed using nanotechnology, promise precise nutrient delivery, enhanced plant uptake, and reduced environmental impact. This article explores the science, benefits, challenges, applications, and future potential of nano fertilizers, evaluating whether they are a revolutionary solution or a supplementary tool in sustainable agriculture (Ayenew *et al.*, 2025; Yadav *et al.*, 2023). Practical insights, recent case studies, and regulatory considerations are also discussed.

Introduction

Agriculture is at a critical juncture. By 2050, the global population is expected to reach 9.7 billion, placing unprecedented demand on food systems. At the same time, the overuse of conventional fertilizers has led to nutrient runoff, soil acidification, greenhouse gas emissions, and declining soil fertility (Demeke *et al.*, 2025). These challenges create an urgent need for innovative solutions that increase crop productivity without compromising environmental sustainability. Nano fertilizers have emerged as a promising technology. By reducing nutrient losses and enhancing nutrient use efficiency, they could redefine crop nutrition strategies (Goyal *et al.*, 2025). This article discusses the science behind nano fertilizers, their practical applications, and the challenges that need to be addressed before they can become mainstream in agriculture.

Understanding Nano Fertilizers

Nano fertilizers are fertilizers in which nutrients are delivered in nanoscale particles (typically <100 nanometers) or nano-coated formulations (Kekeli *et al.*, 2025). Their small size increases surface area and reactivity, allowing plants to absorb nutrients more efficiently.

Types of Nano Fertilizers

Nano-Coated Fertilizers: Nutrients are encapsulated in nanoparticles or coated with nanomaterials for controlled release, reducing losses due to leaching and volatilization (Yadav *et al.*, 2023).

Nano-Emulsions: Nutrients dispersed in a nano-emulsion improve solubility and enable better foliar absorption (Demeke *et al.*, 2025).

Nanoparticles: Nutrients in nanoparticle form interact directly with plant tissues, enabling targeted nutrient delivery (Goyal *et al.*, 2025).

Smart Fertilizers: Integrated with sensors or slow-release technologies, these fertilizers respond to

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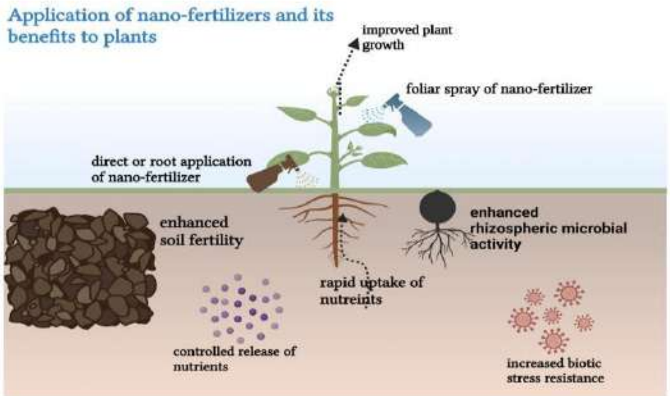
plant needs and environmental conditions (Kekeli *et al.*, 2025).

By enhancing nutrient availability and minimizing environmental losses, nano fertilizers bridge the gap between crop demand and soil nutrient supply.

Benefits of Nano Fertilizers



Enhanced Nutrient Use Efficiency: Nano fertilizers improve nutrient absorption by plants. Studies indicate that nano fertilizers can increase nutrient uptake by 30-50% compared to conventional fertilizers (Yadav *et al.*, 2023). For example, nano urea has been reported to reduce nitrogen application by up to 50% while maintaining yields, making it cost-effective for farmers (Times of India, 2025a).

Controlled Nutrient Release: Conventional fertilizers often release nutrients too quickly, leading to leaching, volatilization, and runoff. Nano fertilizers provide gradual nutrient release, reducing environmental contamination and improving efficiency (Ayenew *et al.*, 2025).

Reduced Environmental Impact: Overuse of nitrogen and phosphorus fertilizers contributes to greenhouse gas emissions, eutrophication, and soil acidification. Nano fertilizers minimize these effects by improving nutrient delivery, promoting sustainable and eco-friendly farming practices (Demeke *et al.*, 2025).

Better Crop Growth and Yield: Nano fertilizers improve germination, root development, biomass accumulation, and yield quality. Field studies in maize, wheat, and rice indicate significant increases in yield and grain quality with nano fertilizer application (Kekeli *et al.*, 2025; Yadav *et al.*, 2023).

Challenges and Limitations

Despite their potential, nano fertilizers face several challenges:

Safety and Toxicity: The small size of nanoparticles can cause oxidative stress in plants or soil microbes (Demeke *et al*., 2025). Long-term safety studies are needed.

High Production Costs: Specialized production techniques increase costs, which may limit adoption by smallholder farmers (Yadav *et al*., 2023).

Regulatory Frameworks: Clear guidelines, labeling standards, and usage instructions are required for safe deployment (Goyal *et al.*, 2025).

Farmer Awareness: Many farmers are unfamiliar with nano fertilizer application techniques, requiring training and extension services (Kekeli *et al.*, 2025).

Applications and Case Studies

Nano Urea in India: India's IFFCO developed nano urea as a high-efficiency nitrogen source. Field trials show that nano urea can replace up to 50% of conventional urea, reducing nitrogen losses while increasing productivity (Times of India, 2025a). Farmers report better crop vigor, earlier maturity, and improved grain quality.

Bio-Fertilizer Integration in Andhra Pradesh: The Andhra Pradesh government promotes bio-nano fertilizers, combining microbial bio-fertilizers with nano nutrient delivery. This reduces chemical fertilizer use by up to 30%, improves soil health, and enhances crop yields, especially in rice and maize (Times of India, 2025b).

Global Perspective: Countries like China, the USA, and Brazil are investing in nano fertilizer research. Nano zinc and nano iron address micronutrient deficiencies in staple crops, improving both yield and nutritional quality (Ayenew *et al*., 2025).

Future Potential

Nano fertilizers are poised to transform agriculture:

Integration with precision agriculture: Combined with soil sensors, drones, and AI, nano fertilizers optimize nutrient application (Kekeli *et al*., 2025).

Customized formulations: Crop-specific nano fertilizers for wheat, maize, or vegetables maximize growth potential (Goyal *et al.*, 2025).

Sustainability and carbon credits: Efficient nutrient use can reduce greenhouse gas emissions and qualify for carbon incentives (Demeke *et al.*, 2025).

Conclusion

Nano fertilizers represent a significant advancement in agriculture, offering solutions for sustainable, high-yield crop production. While they may currently serve as a supplement to conventional fertilizers, responsible implementation could make them a game-changer in the near future. Their success depends on awareness, safety assessments, affordability, and regulatory support. With continued research and adoption, nano fertilizers have the potential to revolutionize modern farming (Yadav *et al.*, 2023; Times of India, 2025a,b).

References

Ayenew, B. M., Satheesh, N., Zegeye, Z. B. and Kassie, D. A. (2025). A review on the production of nanofertilizers and its application in agriculture. *Heliyon*, 11(1): e41243.

Kekeli, M. A., Wang, Q. and Rui, Y. (2025). The role of nano-fertilizers in sustainable agriculture: Boosting crop yields and enhancing quality. *Plants*, 14(4): 554.

Goyal, A., Satheesh, N., Zegeye, Z. B. and Kassie, D. A. (2025). Emerging trends and perspectives on nano-fertilizers for sustainable agriculture. *Discovery Nano*, 20(1): 97.

Yadav, A., Singh, R., Yadav, D., Rathore, S. S., Raj, R., Avasthe, R., Yadav, S. K., Das, A., Yadav, V., Yadav, B., Shekhawat, K., Upadhyay, P. K., Yadav, D. K. and Singh, V. K. (2023). Nanofertilizers: Types, delivery and advantages in agricultural sustainability. *MDPI Agriculture*, 2(2): 19-34.

Demeke, E. D., Ermias, N. B., Gizaw, M., Anbessa, T. T., Mengistu, W. M. and Mekonnen, Y. S. (2025). A comprehensive review on nano-fertilizers: Preparation, development, utilizeation and prospects for sustainable agriculture in Ethiopia. *Nanoscale Advances*, 7(1): 123-145.

Times of India. (2025a). IFFCO posts Rs 3,811 crore profit before tax; sales of Nano fertilizers increase 47%.

Times of India. (2025b). Andhra Pradesh pushes bio-fertiliser revolution in agriculture.

Importance of Training and Pruning in Capsicum in Protected Structure

S. Suriya, R. Sowbarnika and T. Ilakiya

Introduction

Capsicum, a member of the Solanaceae family, is a significant vegetable and spice crop farmed worldwide. The genus Capsicum encompasses a diverse array of peppers, from the sweet, non-pungent bell peppers to the very pungent chilli peppers. The predominant farmed species are *Capsicum annuum*, *Capsicum frutescens*, and *Capsicum chinense*. It is thought to have originated in Central and South America, especially in Mexico, where it has served as both sustenance and medicine for millennia. Currently, it is extensively cultivated in tropical and subtropical areas globally. Capsicum is an exceptionally adaptable crop with numerous applications. The fruits are ingested fresh as vegetables, desiccated and pulverised as spices, or transformed into sauces, pickles, and pastes. The spiciness of chilli peppers is attributed to a chemical known as capsaicin, which is predominantly found in the fruit's placenta. Capsaicin is responsible for the heat and possesses considerable therapeutic and industrial applications, including pain-relieving lotions, pepper sprays, and pharmaceutical items. Conversely, bell peppers are esteemed for their saccharine taste, vivid hues (green, red, yellow, orange), and elevated levels of vitamins C and A. The crop is essential for both for personal use and export markets, considerably impacting the agricultural economy. Besides its culinary significance, capsicum is esteemed for its health advantages, including antioxidant qualities, enhanced metabolism and possible anti-cancer effects. As demand for both fresh and processed capsicum rises, it remains a significant crop for farmers, food businesses, and consumers.

Botanical description

- ✓ Kingdom: Plantae
- ✓ Order: Solanales
- ✓ Family: Solanaceae
- ✓ Genus: Capsicum
- ✓ Species: *C. annuum*

Botany of crop

Flower: The Capsicum flower is bisexual, hypogynous, and typically pentamerous. The flowers are fully developed, featuring calyx, corolla, and both male and female reproductive organs. The diameter of a *C. annuum* flower ranges from 9 to 15 mm. The Capsicum calyx is broadly campanulate, ribbed, around 2 mm in length, and either truncate or undulate, exhibiting weak to significant dentation with 5-7 teeth. The corolla is typically short-tubed in most Capsicum species, generally including 5 petals, while some species may possess 6 to 8 petals.

Fruit: Fruit has considerable variability in shape, size, wall thickness, fleshiness, colour, and pungency, influenced by genetic and environmental

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variables. Fruit is initially dark green in colour at immature stage and becomes light green to yellow colour and finally red in colour during ripening stage.

Pinching: Pinching encourages branching, leading to strong development and an increased quantity of flowers. The apical meristem at the apex of the plant is removed. This is performed after transplantation and prior to the onset of flowering.

Training: Instruction the primary stem of the plant is secured with two plastic twines at the two-stem training level or four plastic twines at the four-stem training level, facilitating training along and attachment to the GI wire grid positioned above the plants. Training operations conducted 25 to 30 days post-transplantation. Vegetation and young shoots were guided along the plastic thread.

Objectives of training

- ✓ Training regulates the morphology of plants
- ✓ Appropriate allocation of fruit-bearing components
- ✓ Pest and disease management
- ✓ To enable the absorption of sunlight by all parts of the plant
- ✓ To establish equilibrium between vegetative and reproductive growth in plants.

Principle of training

Training should commence from the earliest stages of plant development. In plants exhibiting significant apical dominance, the removal of the terminal bud is necessary to promote the development of lateral branches. Drooping branches must be eliminated.

Pruning: Trimming following 25-30 days post-transplantation, the capsicum plants were pruned to retain two to four stems, with intervals of 8 to 10 days between each pruning. The plant exhibits dichotomous branching. The apex of the plant bifurcates at the fifth or sixth node approximately 15 to 20 days post-transplantation. These two branches then bifurcate, resulting in four branches by 25 to 30 days after transplantation. The tip bifurcates at each node, resulting in a robust branch and a feeble branch. Pruning was conducted every 8 to 10 days, resulting in larger, superior-quality, and more productive fruits.

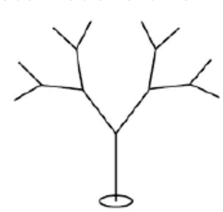
Objectives of pruning

- ✓ To regulate flowering and fruiting.
- ✓ To excise diseased, damaged, and insect-infested portions of the plant, as well as to eliminate weak branches.
- ✓ To reduce the density of flowers and fruits
- ✓ To enhance output in plants that produce new shoots
- ✓ It guarantees sunshine access to fruiting shoots.

Principle of pruning

- ✓ Pruning must be concluded prior to the onset of the flowering season.
- ✓ Infected, compromised, and pest-infested shoots must be eliminated.
- ✓ Prevent damage to the plant during pruning.

Dichotomous branching: Dichotomous branching is a special type of plant growth pattern in which the apical meristem of a stem or



root bifurcates into two equal branches, a process that may recur multiple times. Each division produces two branches of comparable size, resulting in a forked or Y-shaped configuration.

Training

Main Stem Selection: Capsicum plants are cultivated to sustain a predetermined quantity of main stems, usually two or four, contingent upon the cultivar and anticipated production.

Branching: Branches are chosen from the fifth or sixth node of the primary stem and permitted to develop, with the terminals bifurcated into two branches. The chosen branches are vertically secured with plastic threads or alternative materials to a wire grid or framework to offer support and facilitate optimal growth.

Pruning

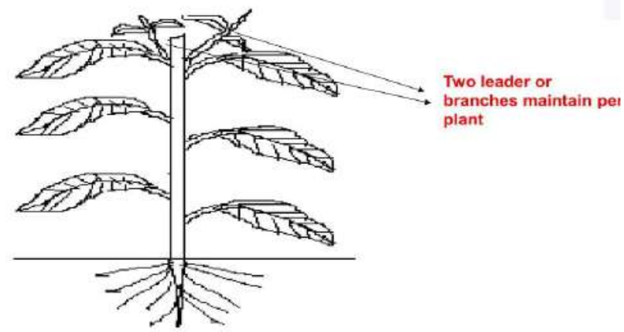
Topping: After transplanting the seedling to the protected structure, cut off the central growing shoot at the tip which enhances the growth of lateral shoots. These lateral shoots helps in increasing the yield

Removal of suckers: The extra grown shoots (suckers) are removed it enhance the growth of mainstem.

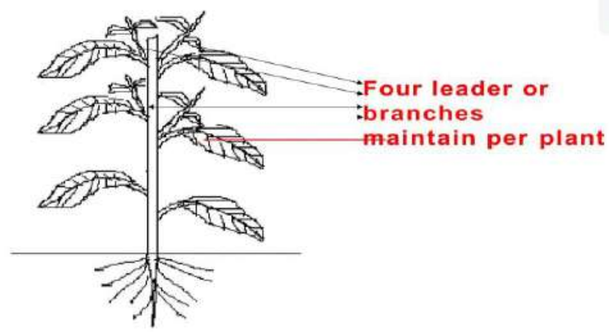
Shedding: The removal of leaves over the fruit is called shedding which helps in colour development in fruit.

Types of pruning

Two-stem pruning: The plant apex splits at the fifth or sixth node, remaining in this state to facilitate the development of two stems. During this pruning, the two primary shoots were preserved as dual leaders, while the lateral shoots were truncated after one or two pairs of leaves.



Four-stem pruning: In quadrifoliate or four stem pruning, two branches were permitted to bifurcate, resulting in four branches. Subsequently, all lateral shoots were removed after one or two pairs of leaves.



Conclusion

In order to maximise output, improve plant health, and guarantee higher-quality fruits, capsicum training and trimming are crucial horticultural techniques. Effective training promotes light penetration, preserves plant structure, and makes managing pests and diseases simpler. Reducing competition for resources and focussing the plant's energy on fruit growth are two benefits of pruning, particularly the removal of undesirable suckers and superfluous foliage. To increase production and space efficiency, shielded horticulture frequently uses techniques like single or two-stem pruning.

Overall, regular training and pruning improve ventilation, reduce the occurrence of disease, and help produce early maturity and consistent fruit size, all of which increase marketable yield and profitability.

References

Barot, D. C., Chaudhari Vishal, M. and Nadoda Nisha, A. (2023). Importance of Training and Pruning in Capsicum Cultivation in Protected Environments.

Dadasaheb, M. G. A. (2024). Effect of training techniques on yield and quality of capsicum under protected cultivation (*Capsicum annuum* var. *grossum* Sendt.) (Doctoral dissertation, Mahatma Phule Krishi Vidyapeeth).

Kesumawati, E., Amalia, R. and Rahmawati, M. (2021). The effect of pruning type on old seedling of chili pepper (*Capsicum annuum* L.) plants to the growth and yield. In IOP Conference Series: Earth and Environmental Science (Vol. 667, No. 1, p. 012031). IOP Publishing.

Zero-Waste Agriculture and Circular Farming Models: A Sustainable Path Forward

Elayarajan M., Suganya S. and Pramila P.

Agriculture today faces the dual challenge of feeding an expanding population while, simultaneously, attempting to conserve natural resources and reduce the environmental impacts. Traditional farming systems are intensive, but they end up generating high quantities of waste products like crop residues, unused or unsold items, animal manure, and agro-industrial by-products (Chiaraluce *et al.*, 2021). The open-field burning of crop residues in the majority of regions results in the release of greenhouse gases and air pollution, while agro-waste quantities in volumes that are too high to utilize end up being wasted, polluting water and soil (Sen *et al.*, 2025). Not only does the practice damage the environment, but it is equally vast wastage of valuable resources that can otherwise be channeled into the agricultural system. In an effort to counter such challenges, zero-waste agriculture and circular farming systems have gained importance across the world. These methods emphasize the philosophy of "nothing goes to waste" so that all by-product of agriculture either organic waste, water, or energy is reused in the same system for productive use. Crop residue can be turned into compost or biochar, animal manure can generate biogas and deposit back nutrients into the soil, and even wastewater can be treated and reused for irrigation. In closed-loop farming systems, the farm is an autarky system in which the output of one process is used as the input for another and hence creates a closed-loop (Duque-Acevedo *et al.*, 2022).

Understanding Zero-Waste Agriculture

Zero-waste farming is an innovative approach that seeks to minimize or completely avoid waste at all stages of farming. Instead of letting outputs such as crop residues, animal dung, or water runoff go to waste, the resources are carefully reused to improve the productivity and sustainability of the farm. Crop residues can be composted or made into biochar, manure can generate biogas as well as improve soil fertility, and runoff water can be harvested or reused for irrigation. Closing these loops, farmers reduce their application of costly chemical fertilizers, lower greenhouse gas emissions, and utilize available resources more effectively. Ultimately, the cycle promotes environmental stewardship while making farm operation more profitable (Canton, 2021).

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Key Practices in Zero-Waste Agriculture

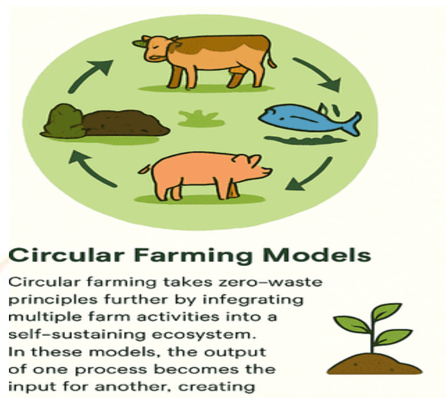
Crop Residue Management: Crop residues are reused as compost or biochar instead of open-field burning. These resources enrich soil organic matter, enhance nutrient supply, and increase carbon sequestration.

Animal Waste Recycling: Manure from livestock can be used as a great organic fertilizer and can even be converted in biogas plants to generate renewable energy, decreasing the dependence of the farm on fossil fuels.

Water Reuse: Farm wastewater, after simple treatment, can be safely recycled for irrigation. This reduces freshwater demand and helps manage water scarcity.

By-Product Utilization: Substandard or excess production, i.e., fruits, vegetables, and grains, can be processed into animal feed, jams, or powders, generating value-added revenue streams for farmers.

Circular Farming Models: Circular agriculture advances beyond zero-waste farming by creating integrated, closed-loop systems where crops, livestock, aquaculture, and agro-industries support each other. Waste from one process becomes input for another for example, crop residues feed animals, manure produces biogas and fertilizes crops, and nutrient-rich aquaculture water irrigates fields. This approach reduces external inputs, improves soil fertility, conserves water, diversifies income, and boosts climate resilience, making farms productive, sustainable, and profitable (Saravanapriya and Mahendiran, 2017).



Implementation Challenges: While the advantages of zero-waste and circular farming are evident, their large-scale adoption faces several challenges. One of the foremost barriers is the lack of awareness among farmers, especially smallholders, about the long-term benefits and practical methods of implementing such models. Many farmers still view waste as a disposal problem rather than a resource to be recycled. Another major challenge is the requirement of technical knowledge and skills. Techniques such as composting, vermicomposting, biochar production, and biogas generation demand proper training to ensure efficiency and safety. Without adequate guidance, farmers may find these practices difficult or uneconomical to adopt. Additionally, the initial investment costs for setting up composting units, biogas plants, or water treatment systems can discourage adoption, particularly in resource-poor rural communities. Access to credit, subsidies, and affordable technologies becomes critical in over-coming these financial constraints (Rex *et al*., 2023). Institutional and policy support also plays a vital role. Strong involvement of government schemes, agricultural extension services, and research institutions is essential to provide technical back-stopping, capacity building, and demonstrations of successful models. Farmer cooperatives and producer organizations can further help by promoting collective action, resource sharing, and knowledge exchange. Thus, while the path to zero-waste and circular farming is promising, overcoming these socio-economic, technical, and financial challenges requires a multi-stakeholder approach that blends policy support, farmer training, and innovative financing models.

Conclusion

Zero-waste and circular farming are trans-formative approaches to sustainable agriculture, turning waste into valuable inputs like compost, biofertilizers, and energy. These practices reduce reliance on synthetic fertilizers, lower costs, decrease pollution, improve soil fertility, and create multiple income streams from by-products such as compost or biogas. They also enhance food security through higher yields and diversified crops. In regions like Tamil Nadu, facing soil degradation, water scarcity, and climate variability, adopting these models can build resource-efficient, climate-resilient farms. Beyond local benefits, circular farming supports global sustainability goals by conserving resources, reducing carbon footprints, and promoting biodiversity, representing a holistic approach that balances productivity, ecological health, and social well-being.

References

Canton, H. (2021). Food and agriculture organization of the United Nations FAO. In The Europa directory of international organizations 2021 (pp. 297-305). Routledge.

Chiaraluce, G., Bentivoglio, D. and Finco, A. (2021). Circular economy for a sustainable agri-food supply chain: A review for current trends and future pathways. *Sustainability*, 13(16): 92-94.

Duque-Acevedo, M., Lancellotti, I., Andreola, F., Barbieri, L., Belmonte-Ureña, L. J. and Camacho-Ferre, F. (2022). Management of agricultural waste biomass as raw material for the construction sector: an analysis of sustainable and circular alternatives. *Environmental Sciences Europe*, 34(1): 70.

Rex, P., Mohammed Ismail, K. R., Meenakshi-sundaram, N., Barmavatu, P., & Sai Bharadwaj, A. V. S. L. (2023). Agricultural biomass waste to biochar: A review on biochar applications using machine learning approach and circular economy. *Chemical Engineering*, 7(3): 50.

Saravanapriya, G. and Mahendiran, R. (2017). Design and development of solar tunnel dryer with control system for large scale drying of agro products. *International Journal of Agriculture Sciences*, ISSN, 0975-3710.

Sen, M., Garai, S., Dutta, S., Rakshit, D., Roy, A., Das, R. and Das, S. (2025). Harnessing Artificial Intelligence for Circular Economy in Agriculture: Reducing Waste and Maximising Efficiency. In Integrating Agriculture, Green Marketing Strategies, and Artificial Intelligence (pp. 317-362). IGI Global Scientific Publishing.

Post-Harvest Treatments in Heliconia: Sustainable, Low-Cost Alternatives to Synthetic Chemicals

Swati and Priyanka Thakur

Abstract

Heliconia, a tropical horticultural crop valued for its unusual inflorescences, encounters severe post-harvest problems like reduced vase life, blackening of the bracts, microbial contamination, wilting, and damage associated with transport. Traditional chemical preservatives like silver nitrate, 8-HQC, sucrose, and chlorine derivatives promote vase life satisfactorily but have drawbacks such as toxicity, high expense, residue buildup, and environmental non-biodegradability. Environmentally friendly, cost-effective alternatives like Aloe vera gel, moringa leaf extract, chitosan coatings, plant extracts, essential oils, and wax coatings have been shown to be of similar effectiveness in vase life, microbial management, and bract quality maintenance with minimal environmental and economic burden. Physical and handling techniques like cold storage, shade handling, hydration pulsing, and biodegradable packaging also add to post-harvest life. Comparative studies show that natural treatments yield long-term ecological and economic advantages, especially for small- and medium-scale farmers. Standardization of dosages, synergistic effects, optimization of biodegradable coatings, and combinations of natural treatments with cold chain management are recommended areas of future studies to optimize post-harvest quality and marketability of Heliconia cut flowers.

Introduction

Heliconia are herbaceous perennials with very attractive and exotic inflorescences (Kress *et al.*, 2001; Loges *et al.*, 2016). Heliconia has been categorized as 'Speciality Flower' due to its exotic unusual inflorescence and has its uses as cut flowers and for landscaping purpose. It is popularly known as lobster claw, wild plantain or false bird of paradise and in Tropical America it is often called as wild bananas. The family Heliconiaceae is native to the American tropical (Kress *et al.*, 2001). It comprise over 250 species, out of which 90 found in Colombia (Berry and Kress, 1991). Whereaas Mexico has 16 native species including *Heliconia veracruzensis* (Gutierrez-Baez et al. 2016) and three species which are endemic to south-eastern Mexico (Villasenor, 2016). Several components of this plant, such as the roots and seeds, are utilised for medicinal purposes.

Species: *H. psittacorum*, *H. hirsuta*, *H. rostrata*, *H. caribea*, *H. latispatha* and other Heliconia species are commercially valuable (Priyadharsini *et al.*,

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2022).

Special Characteristics

- ✓ Variety in vegetative growth and bract arrangement.
- ✓ Tolerance to biotic and abiotic stresses (Naik *et al.*, 2019)
- ✓ Excellent postharvest characteristics such as long vase life (Priyadharsini *et al.*, 2022)

Importance of Post-Harvest Losses in Heliconia

Commercial Value: The longevity and quality of Heliconia cut flowers after harvest are essential for successful commercialization. Poor post-harvest handling leading to wilting, browning, microbial occlusion, and chilling injury during transport reduces their freshness and appearance, negatively affecting market value and consumer acceptance. Maintaining high post-harvest quality extends vase life and reduces losses, making the crop more remunerative for producers and sellers (Malakar *et al.*, 2023).

Ornamental Value: As ornamental plants, Heliconias are prized for their unique, long-lasting colorful bracts. Post-harvest senescence and damage (such as dark spots from chilling or drying of bract tips) diminish their decorative appeal, shortening their usability in floral arrangements and landscaping. Proper handling and storage are necessary to preserve these aesthetic traits (Botini *et al.*, 2022).

Major post-harvest challenges

Short vase life: Heliconia generally exhibits a limited vase life through fast senescence and dehydrating after cutting. Water absorption is naturally low in Heliconia stems due to their broad xylem vessels and poor vascular bonds, leading to faster wilting and lesser turgidity maintenance. Application of preservative solutions, such as sucrose pulsing, can enhance vase life, provided microbial growth in the vase solution is managed (Carrera *et al.*, 2021).

Bract blackening: Bract blackening is a typical post-harvest disorder, particularly when Heliconia is subjected to poor refrigeration or chilling. Dark brown spots and blackening from the center and apex of bracts are symptoms of chilling injury. Blackening and chilling injury become worse when transported from tropical production regions to temperate destinations, leading to quick visual decline (Leite *et al.*, 2015).

Microbial growth: Microbial growth on vase water or on Heliconia surfaces causes vascular blockage, enhanced senescence, rotting, and bad smell. Also, enhanced humidity in storage and transport conditions may encourage microbial activity. Acidifying vase water may prevent vascular blockage and increase vase longevity by inhibiting microorganism growth (Carrera and Arevalo, 2021).

Wilting: Wilting results from poor water balance and inadequate water uptake, as Heliconia's physiology limits post-harvest hydration. Stem trimming, pulsing solutions, and wax coatings can reduce transpiration and help maintain turgidity for a few additional days (Malakar *et al.*, 2023).

Transport issue: Transport is a vital stage that initiates several post-harvest issues.

Temperature variation cold or excessive heat induces physiological disturbances, blackening of the bracts, wilting, and quickening decay. Physical and temperature damages may be caused by unprofessional handling in pooled cargo (Leite *et al.*, 2015).

Conventional Chemical Treatments: Traditional chemical treatments to improve Heliconia vase life are usually based on a variety of synthetic preservatives that address microbial development, water balance, and metabolic processes. Such chemicals have varying modes of action but are characterized by significant limitations regarding toxicity, expense, and environmental longevity. (Malakar *et al.*, 2023).

Typical Synthetic Preservatives and Modes of Action

Silver nitrate ($AgNO_3$): A very effective antimicrobial agent due to their ability to disrupt protein function in bacterial cell walls leading to microbial proliferation in xylem vessels. However, silver compounds are toxic primarily to animal and plant life, as well as to microorganisms, and remained in floral residues. (Malakar *et al.*, 2023).

8-Hydroxyquinoline citrate (8-HQC): Serves as antimicrobial and pH stabilizer in holding solutions. Inhibits microorganism growth that clogs xylem vessels, aiding water uptake. Its activity in Heliconia is inconsistent and residue and biodegradability concerns remain. (Malakar *et al.*, 2023).

Sucrose: Acts as an instantaneous carbohydrate (energy) source to support respiration and extend senescence of picked inflorescences. Pulsing with high sucrose levels supports quality but could foster the growth of microbes when not combined with disinfectants (Costa *et al.*, 2015).

Chlorine compounds (e.g., sodium hypochlorite, NaOCl): Used to inhibit bacterial and fungal infection in vase water. They are effective but cause odor, phytotoxicity, and build up as non-biodegradable residues (Malakar *et al.*, 2023).

Limitations

Cost: Silver nitrate and certain chemical agents are comparatively costly for regular commercial application.

Toxicity: Silver-containing and chlorine chemicals are health risks for workers and environmental toxicity, particularly with ineffective disposal.

Residue Accumulation: Heavy metals like silver remain on cut stems and residues after harvest, creating environmental and food chain issues.

Non-biodegradability: The majority of conventional chemicals are stable and get accumulated in waste streams, giving rise to long-term ecological hazards.

Need for sustainable, low-cost alternatives over synthetic preservatives (chemicals, silver nitrate, STS): Low-cost, eco-friendly substitutes for silver nitrate and STS synthetic preservatives for Heliconia postharvest management include natural anti-microbial substances such as plant extracts and Aloe vera gel and moringa solution, and chitosan coatings and some essential oils (Shokalu *et al.*, 2021).

Grounds for Sustainable Solutions: Synthetic preservatives such as silver nitrate and STS can effectively increase vase life and prevent microbial contamination but are environmentally, health-wise, and expensive in the tropics and developing countries. There is increasing interest in using environmentally friendly, locally available alternatives to enhance the quality and shelf life of cut Heliconia flowers without toxic residues or high costs (Malakar *et al.*, 2023).

Promising low-cost substitute

Aloe vera gel (2-4%): Demonstrated to considerably prolong vase life of Heliconia with 4% gel solution performing better than water and STS in terms of longevity and freshness. It exhibits antimicrobial activity that is effective against microbial population, a green and inexpensive alternative (Shokalu *et al.*, 2019).

Moringa leaf extract (2.5-7.5%): It is a natural preservative solution extending postharvest life compared to inorganic solutions such as calcium chloride. When used with sucrose, it functions especially well with respect to water uptake and flower appearance (Shokalu *et al.*, 2019).

Chitosan coating: Chitosan application from the shells of crustaceans has been shown to improve vase life and stem quality of flowers attributed to its antimicrobial and water-barrier properties (Bañuelos-Hernández *et al.*, 2017).

Plant extracts and essential oils: Compounds from natural sources of cinnamon, clove, oregano, and winter savory possess effective antimicrobial action and the prospect for a decrease in dependence on chemical preservatives in postharvest floriculture and food care. The oils, usually said as micro-emulsions or emulsions, possess the ability to inhibit microbial growth and spoilage (Kovalchuk, 2021).

Wax coatings: Waxes derived from plants reduce water loss, enhance appearance, and preserve tissue without chemical tainting (Carrera *et al.*, 2021).

Physical and handling methods: Physical and handling techniques are becoming more critical for enhancing Heliconia postharvest quality in relation to temperature control, hydration practices, and eco-friendly packaging to confront physiological sensitivity and market needs (Malakar *et al*., 2023).

Cold Storage, Shade Handling, Hydration Pulsing

Cold Storage: Ideal cold storage temperatures of Heliconia are cultivar-dependent, ranging from 14-22°C as the ideal for up to 6-9 days, depending on the variety. Low temperatures below 12°C can lead to chilling injury, including browning of the bract and tissue depression, while increased ambient temperatures promote wilting and metabolic degradation (Botini *et al.*, 2022).

Shade Handling: Shaded conditions during early postharvest handling reduce transpiration stress and water loss, provide a means to maintain inflorescence quality prior to shipping or subsequent processing. (Botini *et al.*, 2020)

Hydration Pulsing: Pulsing with water or natural solutions alone will replace water potential after harvest and enhance turgidity. Natural pulsing compounds like coconut water and dilute sucrose, or those with low antimicrobial activity, can be mixed with clean water for extending shelf life sustainably

Comparative Efficacy

Treatment Type	Vase Life (days)	Bract Color Retention	Microbial reduction	Stem blockage prevention	References
Chemical ($AgNO_3$, 8-HQC, sucrose)	7-11	High	Excellent	Excellent	Malakar *et al.*, 2023
Natural (chitosan, wax, coconut)	6-10	Moderate-High	Good	Good	Bañuelos-Hernández *et al.*, 2017

Economic and Environmental Aspects (Malakar *et al.*, 2023)

Aspect	Natural Treatments	Synthetic (Chemical) Treatments
Cost-Benefit	Generally lower cost inputs (e.g., plant-based extracts, biodegradable coatings). Cost-effective in long-term due to reduced residues and packaging waste. Moderate initial setup costs for some natural preservatives.	Higher cost due to specialty chemicals (silver nitrate, 8-HQC), equipment for chemical handling, and disposal. Often better immediate impact on vase life, but added costs for safety and disposal.
Environmental Safety	Biodegradable, low toxicity, minimal residue buildup. Reduced ecological footprint by avoiding heavy metals and persistent chemicals. Supports sustainability goals.	Toxic residues accumulate (e.g., silver ions). Non-biodegradable materials impact ecosystems. Enhanced risk of soil and water contamination if not managed properly.
Health Safety	Safer for workers and consumers due to absence of toxic metals and harsh chemicals. Reduced risk of chemical exposure.	Requires careful handling due to toxicity; potential health risks for workers and consumers through residues.
Feasibility for Small/Medium growers	Highly feasible. Natural sources often locally available (e.g., banana sheath, sago, coconut water). Easier to implement without specialized equipment. Compatible with low-tech operations typical in tropical regions.	Less feasible due to costs, chemical regulations, and need for trained personnel and protective gear. Chemical procurement and disposal can be barriers in small-scale settings.

(Carrera *et al*., 2021).

Techniques of Wrapping and Eco-Friendly Packaging

Biodegradable Films: Biodegradable wraps utilizing banana sheath fiber, Heliconia leaves, or specialty papers have proved useful in cutting water loss and freshness during transportation (Dodampe *et al.*, 2022).

Banana Sheath and Heliconia Leaves: Experiments point out banana pseudostem and Heliconia leaf composites as strong, biodegradable packaging materials with excellent mechanical properties and user-friendliness over synthetic plastic. Smaller Heliconia leaves can be coated with a gelatin or sago solution for wrapping purposes, providing new, user-friendly biowrappers (Dodampe *et al.*, 2022).

Paper Wraps: Reinforced papers made from crop residues provide ecological advantage and are compostable after use.

Jute and Cloth: Commercial florists also use jute and cloth wrappings with recyclable boxes for bulk shipment and gifting.

Future directions and knowledge gaps in Heliconia postharvest treatments highlight the necessity of the following major areas:

Standardization of dosage and mixtures: There is a strong requirement for standardized procedures in terms of dosage and mixtures of natural treatments like plant extracts, biodegradable coatings, and pulsing solutions for Heliconia. Present practices are highly variable, restricting reproducibility and commercial scale-up (Malakar *et al*., 2023).

Synergistic effects exploration: Examining blends such as sucrose with other plant extracts, or blending natural antimicrobial and antioxidant compounds, may provide synergistic effects that increase vase life and stress tolerance beyond that of treatments given individually (Malakar *et al.*, 2023).

Eco-packaging and biodegradable coatings: Further research is necessary on the best formulations of biodegradable coatings (e.g., waxes, chitosan) and sustainable packaging materials (banana sheath, Heliconia leaves) that are particularly adapted to tropical cut flowers such as Heliconia, including aspects related to mechanical properties, moisture holding capacity, and biodegradability (Sanches *et al.*, 2025).

Integration with postharvest cold chain management: Creating integrated strategies that combine natural treatments with optimized cold storage and transport techniques will maximize sustainability and extend shelf life in the supply chain, taking into consideration the chilling sensitivity of Heliconia (Malakar *et al.*, 2023).

Conclusion

Environmentally friendly, inexpensive postharvest treatments like Aloe vera gel, moringa leaf extract, chitosan coatings, plant extracts, waxes, and natural packaging successfully improve Heliconia cut flower vase life, quality, and microbial safety. Natural alternatives lower environmental and human health risks of synthetic chemicals, are economically viable for small and medium farmers, and promote sustainable floriculture. Future studies need to aim at standardizing doses, studying synergistic effects, maximizing biodegradable coatings, and combining natural treatments with cold chain maintenance in order to achieve optimal postharvest life and marketability.

References

Bañuelos-Hernández, K. P., García-Nava, J. R., Leyva-Ovalle, O. R., Peña-Valdivia, C. B. and Ybarra-Moncada, M. C. (2016). Flowering stem storage of *Heliconia psittacorum* L. f. cv. Trópica. *Postharvest Biology and Technology*, 112: 159-169.

Bañuelos-Hernández, K. P., García-Nava, J. R., Leyva-Ovalle, O. R., Peña-Valdivia, C. B., Trejo, C. and Ybarra-Moncada, M. C. (2017). Chitosan coating effect on vase life of flowering stems of *Heliconia bihai* (L.) L. cv. Halloween. *Postharvest Biology and Technology*, 132: 179-187p.

Berry, F. and Kress, W. J. (1991). Heliconia. An identification guide. Washington: Smithsonian Institution Press.

Botini, A. F., Pereira Alves de França, R., Menezes Cordeiro, M. H., Krause, W. and Silva, C. A. (2022). Productivity and postharvest durability of Heliconiaceae grown in full sun in the Midwest region of Brazil. Revista Ceres. *Scielo Brasil*, 69(6): 678-684.

Gutiérrez-Báez, C., Avendaño-Reyes, S. and Zamora-Crescencio, P. (2016). *Heliconia veracruzensis*, nueva especie de Veracruz, México. *Bouteloua*, 25: 101-103.

Kovalchuk, Y. (2021). Bio-based preservatives: A natural alternative to synthetic additives. *International Journal of Science and Research Archive*, 1(2): 56-70.

Carrera-Alvarado, G., Arévalo-Galarza, M. de, L., Velasco-Velasco, J., de-la-Cruz-Guzmán, G. H., Salinas-Ruíz, J. and Baltazar-Bernal, O. (2021). Treatments to prolong the post-harvest life of *Heliconia wagneriana* Petersen. *Ornamental Horticulture*, 27(4): 476-484.

Carrera-Alvarado, G. and Baltazar-Berna, O. (2021). Solutions to conserve the vase life of *Heliconia* 'Tropics'. *Horticultura Brasileira*, 39(4).

Costa, R. R., Costa, L. C., Carneiro, G. G., Ribeiro, W. S., Barbosa, J. A. and Finger, F. L. (2015). Postharvest quality of *Heliconia wagneriana* pulsed with sucrose. *Acta Horticulturae*, 1060: 139-144.

Dodampe, I. C., Rifnas, L. M., Madushani, W. G. C. and Weerasinghe, S. S. (2022). Development of eco-friendly smart bio-food wrapper using undersized *Heliconia bihai* leaves. *International Journal of Minor Fruits, Medicinal and Aromatic Plants*, 8(2): 86-90.

Kress, W. J., L. M. Prince, W. J. Hahn and E. A. Zimmer. (2001). Unraveling the evolutionary radiation of the families of the Zingiberales using morphological and molecular evidence. *Systematic Biology*, 51: 926-944.

Leite, K. P., Costa, A. S., Pinheiro, P. G. L., Gomes, R. J. and Loges, V. (2015). Postharvest of cut flower *Heliconia stricta* 'Bucky' stored under different conditions. *Acta Horticulturae*, 1060: 235-241.

Loges, V., de Castro, C. E. F., de Castro, A. C. R. and Gonçalves, C. (2016). Characteristics of pendent heliconia for use in landscape and as cut flower. *Ornamental Horticulture*, 22(3): 287-295.

Malakar, M., Paiva, P. D. O., Beruto, M. and da Cunha, Neto. A. R. (2023). Review of recent advances in post-harvest techniques for tropical cut flowers and future prospects : *Heliconia* as a case-study. *Frontiers in Plant Science*, 14: 1221346.

Priyadharsini, R., Padmapriya, S., Rajamani, K. and Senthil, N. (2022). Physiological and Biochemical characteristics of Heliconia genotypes grown in shadenet condition. *The Pharma Innovation Journal*, 11(7): 2268.

Sanches, A. G., Feitosa, E. M. F. and Schwob, A. C. (2025). Longevity and alleviation of chilling injury in Heliconia cut flowers coated with carnauba wax nanoemulsion and sorbitol pulsing solution. *Postharvest Biology and Technology*, 227: 113-625.

Shokalu, A. O., Akintoye, H. A., Olatunji, M. T., Adebayo, A. G. and James, I. E. (2019). Use of organic and inorganic solutions for extending the vase life of cut *Heliconia* 'Golden Torch' flowers. In *Acta Horticulturae*.

Shokalu, A. O., Israel, J., *et al.* (2021). Aloe vera and STS solution on microbial population and vase life of Heliconia cut flowers. *Ornamental Horticulture*, 27(4): 470-475.

Agrivoltaic Systems in Agriculture and Allied Sciences: Towards a Sustainable Future

Devi Lal Jat, Manisha Rathore and Kirti Gour

Abstract

Agriculture today faces immense pressure to produce sufficient food while coping with challenges such as climate change, and growing energy demands. Agrivoltaics, also known as agro-photovoltaic (APV), offers an innovative solution by integrating solar photovoltaic energy generation with agricultural production on the same piece of land. This dual-use system not only enhances land productivity and resource efficiency but also contributes to food and energy security while improving microclimates and water efficiency. The scope of agrivoltaics extends beyond crop cultivation to include allied sectors such as horticulture, livestock, aquaculture, and agroforestry making it a holistic model for sustainable rural development. From an economic perspective, agrivoltaics generates new income streams, reduces production risks, and strengthens farm resilience. This article discusses the concept, design, applications, benefits, economic dimensions, challenges, and policy prospects of agrivoltaic systems, emphasizing their potential to promote sustainable agriculture, climate resilience, and livelihood security in India.

Introduction

Agriculture is a fundamental sector of the global economy and the cornerstone of food security, providing livelihood opportunities to billions of people across the world. In recent years, however, agriculture has been experiencing a multitude of challenges such as erratic climate patterns, rising temperatures, declining soil fertility, and shrinking availability of cultivable land. According to international projections, food demand will rise significantly by 2050, while simultaneously, the energy sector is transitioning towards renewable sources to meet sustainability goals. Solar energy has become one of the most rapidly expanding forms of renewable energy, yet the large land requirements of solar parks often create a conflict between energy and food production. To address this concern, the concept of agrivoltaics has emerged as an innovative dual-use strategy that allows simultaneous agricultural activities and solar energy generation on the same land. The term agrivoltaics was first introduced by Goetzberger and Zastrow in Germany in 1982.

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The principle is based on installing solar photovoltaic panels in a manner that allows sufficient sunlight penetration for crop growth while harvesting energy for electricity generation. The concept has evolved into practical systems with successful implementations in countries such as Japan, France, China, and the United States. India, with its vast solar energy potential and agricultural dependence, is also exploring agrivoltaics as a way to balance food and energy needs while addressing rural income insecurity.

Agrivoltaic System: Concept and Design Principles

Figure 1. The different agrivoltaic systems

Agrivoltaic systems involve integrating solar panels into farmland in a manner that allows both agricultural production and energy harvesting. The design of such systems depends on crop type, geographic region, and energy requirements. Panels are often installed at a height of two to five meters above ground level, enabling the continuation of farming activities, including the use of machinery. The spacing and arrangement of panels are carefully planned so that crops receive adequate sunlight for photosynthesis while optimizing solar electricity production. Modern designs incorporate different models such as fixed-tilt systems, rotating panels, and vertical bifacial modules. Water management is another critical component, as panels reduce evaporation from soil while rainwater harvested from their surfaces can be directed into irrigation systems. Smart sensors and AI-based monitoring help maintain the balance between crop yield and energy output.

Applications in Agriculture and Allied Sciences:

The scope of agrivoltaics is not confined to crop cultivation alone; it extends into several allied sectors that play an equally important role in rural economies. In crop production, research has shown that partial shading from solar panels helps in reducing heat stress and water loss, thereby improving water-use efficiency. Crops such as tomatoes, spinach, lettuce, and maize have demonstrated stable or even improved yields under agrivoltaic systems. In regions prone to heatwaves and drought, the microclimatic benefits of panel shading are particularly valuable. In horticulture, agrivoltaics can be used to protect high-value fruit and vegetable crops that are sensitive to extreme sunlight and temperature fluctuations. Fruits like grapes, apples, and strawberries benefit from partial shading, which reduces the risk of sunburn and enhances product quality. Climbing crops also adapt well to vertical solar structures, making agrivoltaics a versatile solution for horticultural production. In livestock farming, the shading provided by solar panels improves animal welfare by reducing heat stress, which is particularly important in tropical and arid regions. Improved thermal comfort enhances animal productivity, while solar power supports irrigation, cooling, and milking operations. In some parts of Europe, sheep grazing under solar panels has become a common practice, providing vegetation management while generating energy. In the field of aquaculture, floating solar photovoltaic systems have emerged as an innovative integration. These systems not only generate electricity but also reduce water evaporation from ponds and reservoirs. By providing shade, they also help maintain cooler water temperatures, which benefits fish health. Solar-powered aerators and water pumps further enhance aquaculture efficiency. Such models are gaining popularity in Southeast Asia and can be adapted to India's inland fishery sector. Agroforestry also stands to benefit from agrivoltaics, as solar panels can be combined with tree plantations to promote carbon sequestration and biodiversity. Shade-loving crops such as turmeric, ginger, and medicinal herbs can thrive under the diffused light conditions created by solar panels. Additionally, fodder crops grown under solar structures contribute to livestock nutrition, creating a holistic farming system.

Economic Dimensions of Agrivoltaics

Dual Income Generation and Risk Diversification : Agrivoltaic systems allow farmers to earn simultaneously from crop production and electricity generation. Surplus energy can be sold to the grid or used for value-added operations such as irrigation, processing, and storage. Studies in Japan and India indicate that integrating solar energy with agriculture can increase farm income by 30-60 % compared to traditional systems (Majumdar and Pasqualetti, 2018; Weselek *et al*., 2019). This dual-income model cushions farmers against price volatility and climatic uncertainties.

Cost-Benefit and Profitability: Though the initial investment is substantial, long-term returns are favorable. The typical payback period ranges from 6 to 10 years, depending on energy tariffs, system design, and government incentives. Agrivoltaic systems reduce input costs by lowering irrigation needs and enabling energy self-sufficiency. Under the PM-KUSUM scheme, farmers receive financial support for solar pumps and grid-connected systems, further improving economic feasibility.

Employment and Rural Development: The agrivoltaic value chain creates employment in installation, panel cleaning, maintenance, and monitoring. It encourages rural entrepreneurship through micro-enterprises involved in fabrication and service provision. Consequently, agrivoltaics supports local job creation, skill development, and youth engagement in the renewable energy sector.

Environmental Valuation and Carbon Economics : Agrivoltaics deliver measurable environmental benefits with economic value. Reduced emissions and improved soil health contribute to ecosystem service valuation, which can be monetized through carbon credits. A 1-MW agrivoltaic system can offset approximately 1,200-1,500 tons of CO_2 annually, valued at ₹15-20 lakh in voluntary carbon markets (Hoffacker *et al.*, 2020).

Policy Economics and Financial Mechanisms:

From a policy-economic perspective, agrivoltaics represent an opportunity for public-private partnerships in sustainable land use. Subsidized loans, feed-in tariffs, and renewable energy purchase obligations can make these systems financially viable. Integrating agrivoltaic projects into green financing frameworks and agricultural credit schemes would promote inclusive and scalable adoption.

Benefits of Agrivoltaics: Agrivoltaics offers a wide range of benefits that extend beyond food and energy production. One of the most significant advantages is land use efficiency, as the system enables the dual purpose of food cultivation and electricity generation without requiring additional land resources. This is particularly crucial in countries with high population density and limited land availability. Another benefit lies in climate resilience. Solar panels create a favorable microclimate that protects crops from extreme weather conditions such as heat waves, hailstorms, and heavy rainfall. The reduction in evapotranspiration under shaded conditions also leads to substantial water conservation, which is critical in arid and semi-arid regions. Studies indicate that water requirements of crops may be reduced by 15-25% under agrivoltaic systems. Economically, it strengthens farm income stability.

Challenges and Limitations: Despite the numerous benefits, agrivoltaics faces several challenges that hinder its widespread adoption. The high initial investment required for installation remains one of the biggest obstacles, particularly for smallholder farmers. The cost of setting up solar panels, supporting structures, and maintenance systems often exceeds the financial capacity of rural households, necessitating government subsidies and credit facilities. Policy barriers also play a significant role. In many regions, land is strictly classified as either agricultural or non-agricultural, creating regulatory difficulties in implementing dual-use systems. In addition, the lack of clear guidelines on energy sharing, grid connectivity, and pricing discourages farmer participation. Technical issues such as crop compatibility also need attention. Not all crops are suited to shaded environments, and region-specific research is required to identify varieties that can thrive under agrivoltaic conditions. Limited technical expertise and infrastructure in rural area also hinder adoption. Moreover, power evacuation from remote rural areas remains a challenge due to weak grid connectivity.

Future Prospects and Policy Recommendations

Looking ahead, agrivoltaics has the potential to become a cornerstone of sustainable agricultural development. Research should identify optimal panel design and crop combinations for each agro-climatic zone. Technological advancements, including semi-transparent panels, mobile solar arrays, and AI-driven systems, will further enhance the efficiency and adaptability of agrivoltaics. Policy support will be critical in scaling up agrivoltaic systems. Governments should offer financial incentives, and clear land use and energy-sale guidelines to make these systems more attractive to farmers. Programs such as India's PM-KUSUM scheme can be aligned with agrivoltaic adoption, enabling farmers to benefit both from renewable energy generation and sustainable agricultural practices. Capacity building and awareness programs will also play an important role. Training farmers, agricultural engineers, and technicians in agrivoltaic design, operation, and maintenance will ensure that the technology is implemented effectively. Given its high solar potential and dependence on agriculture, India has an opportunity to become a global leader in agrivoltaics by integrating it into national strategies for food-energy-water security.

Conclusion

Agrivoltaics is a forward-looking approach that unites food security with renewable energy generation. By maximizing land-use efficiency, conserving water, and diversifying farm income, it offers a sustainable response to the major challenges of modern agriculture. Although high costs, policy gaps, and technical limitations persist, these can be mitigated through targeted research, supportive policies, and active farmer participation. Integrating renewable energy with crop production, agrivoltaics enhances land productivity, promotes climate resilience, and strengthens rural livelihoods. With strong institutional frameworks and economic incentives, it can transform India's agricultural landscape. As the world advances toward carbon neutrality and sustainable farming, agrivoltaics stands out as a defining innovation that bridges renewable energy and agricultural growth shaping the future of agriculture and allied sciences.

References

Dupraz, C., Marrou, H., Talbot, G., Dufour, L., Nogier, A. and Ferard, Y. (2011). Combining solar photovoltaic panels and food crops for optimizing land use: Towards new agri-voltaic schemes. *Renewable Energy*, 36(10): 2725-2732.

FAO. (2023). The State of Food and Agriculture 2023. *Food and Agriculture Organization of the United Nations.*

Goetzberger, A. and Zastrow, A. (1982). On the coexistence of solar energy conversion and plant cultivation. *International Journal of Solar Energy*, 1(1): 55-69.

Hoffacker, M. K., Allen, M. F. and Hernandez, R. R. (2020). Land-sparing opportunities for solar energy development in agricultural land-scapes. *Nature Sustainability*, 3(4): 365-372.

Majumdar, D. and Pasqualetti, M. J. (2018). Dual use of agricultural land: Introducing agrivoltaics in India. *Renewable and Sustainable Energy Reviews*, 73: 125-134.

Sahu, A., Yadav, N. and Sudhakar, K. (2016). Floating photovoltaic power plant: A review. *Renewable and Sustainable Energy Reviews*, 66: 815-824.

Weselek, A., Ehmann, A., Zikeli, S., Lewandowski, I., Schindele, S. and Högy, P. (2019). Agro-photovoltaic systems: Applications, challen-ges and opportunities - A review. *Agronomy for Sustainable Development*, 39 (4): 35

Farming in the Air: Aeroponics as a Sustainable Alternative to Soil-based Farming

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Abstract

Aeroponics is an innovative, soil-less cultivation system in which plant roots are suspended in air and supplied with a fine mist of nutrient-rich solution. This technique allows precise control over water, nutrients, and oxygen, leading to faster plant growth, higher yields, and efficient resource use. Compared to conventional soil-based farming, aeroponics requires up to 90% less water, eliminates the need of chemical treatments to soil. It also reduces disease transmission since roots are not in contact with soil. As global agricultural land and water resources decline, aeroponics presents a sustainable, eco-friendly alternative that can support food security in both urban and rural areas.

Introduction

Aeroponics is a method of growing plants without soil, where roots are suspended in air and misted with nutrient-rich solutions. The term comes from the Latin words "aero" means air and "ponic" means work. Unlike traditional soil-based agriculture or other soilless systems like hydroponics, aquaponics, or in-vitro culture, aeroponics allows for more precise control of environmental conditions, leading to faster growth rates, better nutrient uptake, and higher yields. One key advantage is its efficient use of water up to 90% less than conventional methods and minimal use of growing media, which reduces disease risk and improves plant health. Aeroponics is now being successfully used in regions such as South America, parts of Africa, and especially in countries like China and Korea for the commercial production of high-quality potato seed tubers (Lakhiar *et al.*, 2018). In Europe, this technology has only recently gained attention for potato mini tuber production, driven by the demand for clean, disease-free seed. Aeroponics is also being explored for a wide range of crops, including tomatoes, lettuce, cucumbers, and some ornamental plants. Research has shown that compared to hydroponic systems, aeroponics offers better root aeration, fewer diseases issues, and unrestricted root growth due to minimal contact with any support structures. Aeroponics is proving to be a sustainable and innovative solution for modern agriculture and is even utilized in NASA's space research programs due to its efficiency and suitability for controlled environments.

Principles of Aeroponics

Aeroponics is a soil-less cultivation technique where plant roots are suspended in air inside a

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closed or semi-closed chamber. This system requires a well-designed setup comprising spray nozzles, pipes, a timer, a nutrient pump, and a storage reservoir. The nutrient solution is prepared by mixing essential minerals with water and is filtered and pressurized before being delivered as a fine mist to the plant roots. Because the roots are not buried in soil, they receive much more oxygen than in conventional farming. Misting typically occurs every 2-3 minutes for a few seconds, ensuring roots remain hydrated and nourished without becoming water-logged. A key component of the system is the misting chamber, which must be lightproof to avoid algal growth and maintain root health. The size of the mist droplets is also vital; droplets that are too large can limit oxygen availability, while overly fine droplets can lead to excessive root hair development, hindering lateral root growth. Therefore, achieving the optimal droplet size is essential for effective nutrient absorption and healthy root development.

Fig. 1: Fully completed aeroponics screen house

Fig. 2: Growth of yam on experimental boxes

Application of Aeroponics in vegetables and tuber crops

Yams: Aeroponics technology presents a promising and effective method for yam propagation. It has been successfully applied to propagate genotypes of both *Dioscorea rotundata* and *Dioscorea alata* using pre-rooted as well as freshly cut vine segments. Studies have demonstrated that vine cuttings taken from five-month-old yam plants achieved a high rooting success rate up to 95% within just 14 days under aeroponics conditions. This highlights the system's potential for rapid and efficient yam multiplication, making it a valuable tool for improving seed yam production in controlled environments.

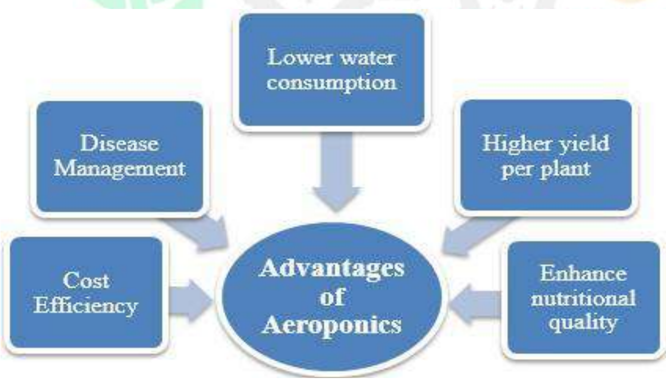
Potato: C.B. Christie and M.A. Nichols (2004) utilized aeroponics to efficiently mass-produce healthy seed potatoes and gourmet early (new) potatoes. In aeroponics, successful tuber production depends on precisely managing tuber initiation, typically through intermittent irrigation or temporary plant stress. A key benefit of this approach is the ability to synchronize tuber formation, resulting in the simultaneous production of a large number of uniform tubers.

Lettuce: Luo *et al*. (2009) developed an effective method for producing hearted lettuce in tropical climates using aeroponics combined with root zone cooling. Additionally, elevated root zone CO_2 and higher air temperatures were found to influence photosynthetic gas exchange, nitrate uptake and total reduced nitrogen content in aeroponically grown lettuce

Tomato: Growing tomatoes with aeroponics has shown great results compared to traditional soil methods. Plants grew taller (85 cm), had more leaves, longer roots, and greater overall health. The real win was in the harvest; each plant produced about 40 tomatoes weighing 850 grams, while soil-grown plants gave only 30 tomatoes and 650 grams. This boost comes from how aeroponics works, delivering nutrients and oxygen directly to the roots, helping plants grow faster and produce more. It's a smart, efficient way to grow healthier, more productive tomato plants.

Advantages of Aeroponics System

Aeroponics offers several advantages that make it an efficient and sustainable method of cultivation.



Limitations of Aeroponics

While aeroponics offers many benefits, it also comes with some limitations.

Conclusions

Aeroponics technology represents a major step toward sustainable and resource efficient agriculture. By replacing soil with a controlled air and mist environment, it minimizes water and land usages. This method is ideal for regions facing soil degradation or water scarcity. Although the initial setup cost and technical expertise required are relatively high, continuous research and innovations are making aeroponics more accessible.

References

Christie, C. B. and Nicholas, M. A. (2004). Aero-ponics - A production system and research tool. *Acta Horticulturae*, 648: 289-295.

Lakhiar, I. A., Gao, J., Syed, T. N., Chandio, F. A. and Buttar, N. A. (2018). Modern plant cultivation technologies in agriculture under controlled environment: A review on aeroponics. *Journal of Plant Interactions*, 13(1): 338-352.

Luo, H. Y., Lee, S. K. and He, J. (2009). Integrated effects of root-zone temperatures and phosphorus levels on aeroponically-grown lettuce (*Lactuca sativa* L.) in the tropics. *The Open Horticulture Journal*, 2: 6-12.

The Journey of India's Solar Power

Tirunagari Kranthi Priya and Pasagada Gayatri

Introduction

India's journey with solar energy reflects its determination to create a cleaner, greener, and more self-reliant future. Blessed with abundant sunlight for most of the year, the country recognized the immense potential of solar power as a sustainable energy source. The turning point came with the launch of the National Solar Mission in 2010, under the National Action Plan on Climate Change, which aimed to promote the development and use of solar energy across the nation. This mission marked the beginning of a new era in India's energy sector, shifting focus from conventional fossil fuels to renewable and eco-friendly alternatives. Over the years, India has emerged as one of the global leaders in solar power generation, achieving some of the lowest solar electricity costs in the world. Large-scale solar parks like the Bhadla Solar Park in Rajasthan, rooftop installations in urban areas, and schemes such as KUSUM and PM Surya Ghar Muft Bijli Yojana have played a major role in making solar energy accessible to both rural and urban communities. The solar journey not only represents technological progress but also symbolizes India's growing commitment to sustainability, innovation, and environmental responsibility.

Historical Journey of Solar Energy in India

India's solar energy journey began in the early 2000s, when the government recognized the need to shift from fossil fuels to renewable sources. The Electricity Act of 2003 encouraged renewable power generation and laid the foundation for future solar policies.A major turning point came with the launch of the Jawaharlal Nehru National Solar Mission (JNNSM) in 2010, under the National Action Plan on Climate Change. Its aim was to promote large-scale solar projects, reduce costs, and make solar power accessible across the country. Since then, India has made rapid progress with initiatives like the KUSUM Scheme for farmers and the Solar Park Scheme for large projects. Mega installations such as the Bhadla Solar Park in Rajasthan have made India one of the lowest-cost producers of solar power globally. With continuous government support, technological advancements, and private participation, India has transformed solar energy from a small-scale idea into a major driver of its clean energy revolution.

Current Status and Achievements of Solar Energy in India

India has emerged as one of the world's leading countries in solar energy production, thanks to strong policies and large-scale investments. The country's installed solar capacity has grown rapidly over the past decade, reaching over 80 GW by 2025, making it a key part of India's renewable energy mix.

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The government's initiatives like the PM Surya Ghar Muft Bijli Yojana and KUSUM Scheme have helped promote solar rooftops and solar-powered irrigation, benefiting both urban households and rural farmers. Massive projects such as the Bhadla Solar Park in Rajasthan and Pavagada Solar Park in Karnataka have positioned India as a global leader in affordable solar power generation. The country has achieved some of the lowest solar energy costs in the world, proving that clean energy can be both sustainable and economical. These achievements reflect India's growing commitment to reducing carbon emissions, ensuring energy security, and moving closer to its target of 500 GW of renewable energy capacity by 2030.

Challenges and Future Prospects of Solar Energy in India

Despite significant progress, India's solar energy sector still faces several challenges. A major issue is the dependence on imported solar panels and equipment, mainly from countries like China, which affects local manufacturing growth. Other challenges include land availability, storage limitations, and delays in subsidy distribution. Integrating solar power into the existing grid system and ensuring 24-hour power supply also remain difficult due to the variable nature of sunlight. Looking ahead, India has set ambitious goals to achieve 500 GW of renewable energy capacity by 2030 and net-zero emissions by 2070. The future of solar energy lies in developing domestic manufacturing, improving battery storage technologies, and promoting rooftop and floating solar systems. With strong policy support, technological innovation, and youth participation, India's solar journey promises a bright and sustainable future for generations to come.

Conclusion

The journey of solar energy in India is a story of vision, innovation, and progress toward sustainability. From the launch of the National Solar Mission in 2010 to becoming one of the world's top solar power producers, India has shown remarkable commitment to clean energy development. As India continues its mission toward a carbon-free future, solar energy stands at the heart of this transformation. By overcoming existing challenges and investing in new technologies, India is paving the way for an energy-secure and environmentally responsible future. The country's solar journey is not just about generating power it represents hope, sustainability, and a brighter tomorrow for all.

Picrorhiza kurroa Royle ex Benth.: An Endemic Botanical Resource for Enhancing Agricultural Resilience and Economic Security in the Mountain Agroecosystems of Uttarakhand

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Abstract

This article examines the significant potential of *Picrorhiza kurroa* Royle ex Benth. (Scrophulariaceae), an endangered Himalayan hepatoprotective herb, as a strategic high-value crop to augment the agricultural prosperity and livelihood security of smallholder farmers inhabiting the challenging terrains of Uttarakhand, India. The analysis focuses on its unique ecophysiological adaptations, unparalleled phytochemical profile driving substantial medicinal demand, inherent resilience against biotic pressures, and emerging market dynamics favoring sustainable cultivation. Overexploitation has threatened its natural pockets. The strategic integration of mountain farming systems of this crop improves local farmer's incomes, supports conservation of this vital botanical resource for future generations.

Introduction

The agrarian landscape of hilly regions of Uttarakhand is characterized by fragmented land-holdings, topographical constraints, climatic extremities, escalating human-wildlife conflict, and limited access to economic markets. Conventional subsistence agriculture often yields marginal economic returns, contributing to rural outmigration and vulnerability. Within this context, the cultivation of regionally adapted, high-value medicinal and aromatic plants (MAPs) present a viable pathway for sustainable economic development. *Picrorhiza kurroa* (commonly known as Kutki or Kadwi), an indigenous species endemic to the high Himalayas, emerges as a particularly promising candidate due to its intrinsic suitability to mountain conditions IUCN endangered (EN) status necessitating *ex-situ* conservation through cultivation and robust comme-rcial demand driven by its irreplaceable therapeutic properties.

Botanical Introduction and Eco-physiological Specificity

Picrorhiza kurroa is a small, perennial rhizomatous herb endemic to the alpine and sub-alpine zones (typically 3000-4500 masl) of the Himalayan range. Its primary economic value resides in the dried rhizomes and roots, characterized by a distinctive bitter taste.

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Crucially, its successful cultivation is intrinsically linked to specific high-altitude eco-physiological requirements:

Obligate Altitudinal Range: Optimal growth and bioactive compound synthesis occur strictly within the cool, high-altitude environments (generally above 2,500 m) of Uttarakhand. Lower elevations fail to provide the requisite diurnal temperature fluctuations, light quality and seasonal photo-periodicity.

Low Temperature Imperative: Low temperatures stimulating the secondary metabolism as a protective adaptation, resulting in increased synthesis of stress-related phytochemicals with medicinal relevance. Thus, cultivating or harvesting *P. kurroa* under cooler conditions maximizes alkaloid yield and enhances the plant's pharmacological value. Seed germination also requires low temperature stratific-ation, for germination it is difficult in lowlands conditions.

Edaphic and Microclimatic Preferences: The species thrive on well-drained, rocky, steep slopes, short growing season with permafrost condition. These specific microclimatic conditions, only found in high altitude areas.

Perennial Growth: As a perennial, it offers potential for sustained harvests following an initial establishment period (typically 3-4 years through rhizome cuttings), reducing annual replanting costs and soil disturbance. These requirements render *P. kurroa* cultivation economically viable and ecologically appropriate almost exclusively within the higher elevations of Uttarakhand, presenting a unique niche opportunity inaccessible to lowland agriculture.

Pharmacological Significance and Therapeutic Value

The immense commercial and therapeutic value of *P. kurroa* stems from its complex profile of bioactive iridoid glycosides and phenolics. The principal bioactive constituents, collectively known as "kutkin," are a standardized mixture of picroside-I and kutkoside. These compounds confer a wide spectrum of validated pharmacological activities:

Hepatoprotective and Choleresis: Demonstrates potent efficacy against various hepatopathies, including viral hepatitis, alcoholic liver disease, and toxin-induced damage, primarily by enhancing bile secretion (choleretic effect), reducing oxidative stress, and modulating liver enzyme profiles.

Immunomodulation: Exhibits significant immuno-stimulatory properties, enhancing macrophage activity and cytokine regulation.

Anti-inflammatory and Antioxidant Activity: Effective in mitigating inflammatory processes, particularly in respiratory conditions like asthma and bronchitis, and combating oxidative damage through free radical scavenging.

Gastroprotective Effects: Acts as a digestive stimulant (stomachic) and protects gastric mucosa.

Febrifuge and Anti-allergic Properties: Tradition-ally and pharmacologically utilized for managing fevers and allergic responses.

These properties underpin its indispensable role in Ayurveda, Siddha, Unani, and increasingly, modern phytopharmaceutical formulations targeting liver disorders, immune support, and respiratory health.

Allelopathic Defense: Mitigating Crop Depredation by Wildlife

A critical advantage for high-altitude farmers is the species inherent resistance to herbivory, significantly reducing crop losses compared to conventional staples:

Chemical Deterrence: The rhizomes and foliage contain high concentrations of intensely bitter secondary metabolites, notably cucurbitacin (triterpenoids) and iridoid glycosides. These compounds are highly unpalatable and often toxic to a wide range of wild herbivores, including deer (e.g., *Moschus chrysogaster*), wild boar (*Sus scrofa*), monkeys (*Macaca mulatta*), and even free-ranging livestock.

Reduced Dependency on Physical Barriers: This natural chemical defense substantially diminishes the necessity for costly and ecologically disruptive fencing infrastructure, a major expense and management challenge for other crops in wildlife-prone areas. This translates directly to lower production costs and minimized economic losses from grazing/browsing.

Promoting Coexistence: Cultivation of unpalatable MAPs like *P. kurroa* offers a strategy for sustainable agricultural income generation that minimizes negative interactions with local fauna, contributing to biodiversity conservation goals.

Market Dynamics and Commercial Viability

The demand for authentic *P. kurroa* raw material is substantial and exhibits a positive growth trajectory, driven by several factors:

Endangered Status and Regulatory Framework: Listed as "Endangered" on the IUCN Red List and, *P. kurroa* faces severe threat from unsustainable wild harvesting. Regulatory restrictions on wild collection (e.g., through the Forest Rights Act and state forest departments) have drastically constricted legal supply, creating a significant market vacuum.

Pharmaceutical Industry Demand: Major national and international Ayurvedic, nutraceutical, and phytopharmaceutical companies (e.g., Dabur, Himalaya Drug Company, Zandu, Patanjali) require large, consistent, and legally sourced quantities of high-quality rhizomes for flagship hepatoprotective and immunomodulatory products.

Price Premium for Cultivated Material: Sustainably cultivated *P. kurroa*, particularly if organically certified, commands a significant price premium over dwindling and often adulterated wild stocks. Current market prices for dried, quality rhizomes are robust and offer substantially higher returns per unit area than many traditional hill crops (e.g., potatoes, temperate vegetables).

Export Potential: Growing global demand for authentic Ayurvedic herbs and standardized botanical extracts further expands the market beyond domestic consumption.

Institutional Support: Government initiatives like the National Medicinal Plants Board (NMPB) and state horticulture/agriculture departments provide subsidies, technical support, and market linkage schemes specifically promoting the cultivation of endangered high-value MAPs like *P. kurroa*.

Secondary Products and Value Chain Integration

While the primary economic product is the dried rhizome/root, cultivation offers potential for deriving supplementary value:

Propagation Material: Seeds and rhizome divisions from cultivated stock provide a valuable source for expanding cultivation programs and supplying nurseries, creating an additional revenue stream.

Biomass Utilization: Post-harvest aerial biomass (stems, leaves), while lacking the primary bioactive compounds of the rhizome, can be composted effectively to recycle nutrients and improve soil organic matter content for subsequent crops within integrated farming systems.

Value-Added Processing (Potential): Farmer Producer Organizations (FPOs) or cooperatives could explore primary processing (e.g., controlled drying, coarse powdering) or potentially collaborate with extract manufacturers to produce standardized powders or simple extracts, capturing a larger share of the final product value locally. This requires investment in infrastructure, technical training, and stringent quality control protocols adhering to Good Agricultural and Collection Practices (GACP) and Good Manufacturing Practices (GMP).

Conclusion

Picrorhiza kurroa represents a paradigm-shifting opportunity for agricultural diversification and economic enhancement within the fragile yet biodiverse montane agroecosystems of Uttarakhand. Its obligate adaptation to high-altitude conditions creates a unique comparative advantage for hill farmers. The convergence of its critically endangered status, irreplaceable medicinal value, inherent resistance to major biotic stressors like wildlife depredation, and strong market demand driven by regulatory and sustainability imperatives presents a compelling case for its promotion as a cornerstone crop. Strategic investment in: Scientific Cultivation, Robust Extension Services, Organized Market Linkages, Value Chain Development and Quality Assurance Systems is essential to unlock its full potential. By fostering the sustainable cultivation of *P. kurroa*, Uttarakhand can simultaneously achieve critical biodiversity conservation goals, empower its high-altitude farming communities with significantly enhanced and resilient livelihoods, and establish itself as a global leader in the ethical production of high-value Himalayan medicinal botanicals. This integrated approach promises to transform a threatened wild resource into a pillar of sustainable agricultural wealth for the hills.

Key Diseases Affecting Acid Lime in Maharashtra and their Integrated Management Strategies

Digvijay R. Chavan, Sagar A. Karande and Dattarao R. Bhise

Abstract

Acid lime (*Citrus aurantifolia*) is a vital horticultural crop in India, with Maharashtra emerging as a key production hub. Despite its rising output and economic relevance, acid lime cultivation faces serious threats from a spectrum of diseases that compromise yield, fruit quality, and market access. This article presents a comprehensive overview of four major acid lime diseases citrus canker, gummosis, citrus tristeza, and Huanglongbing (HLB) highlighting their symptoms, causal organisms, epidemiology, and management strategies. Each disease is examined for its biological impact and economic consequences, including premature fruit drop, tree decline, and increased input costs. The study emphasizes the need for integrated disease management, including resistant rootstocks, vector control, and sanitation practices. By synthesizing current knowledge and field-level observations, the article aims to support researchers, extension workers, and citrus growers in mitigating disease pressure and sustaining acid lime productivity in vulnerable agro-climatic zones.

Introduction

Acid or Kagzi lime (*Citrus aurantifolia*) is a commercially important fruit crop cultivated across tropical and subtropical regions. India is major contributor of global acid lime production with nationwide cultivation. In country, Maharashtra is emerging as a key production hub. Maharashtra plays the significant role in India's citrus economy, second only to Andhra Pradesh in terms of area under acid lime cultivation (Anonymous, 2025). Despite its economic significance, acid lime production is severely constrained by a range of diseases that affect its growth, yield, and marketability. Among the major diseases, citrus canker, gummosis, citrus tristeza and Huanglongbing (HLB) are particularly destructive. These diseases are caused by diverse pathogens including bacteria, fungi, virus and phloem-restricted bacteria, and manifest through symptoms such as leaf lesions, fruit blemishes, twig dieback, gum exudation, and overall tree decline. Their economic impact is profound ranging from reduced fruit quality and premature drop to complete crop failure and nursery destruction. Infected orchards often require increased investment in plant protection measures, replanting, and disease surveillance, while quarantine restrictions on diseases like citrus canker and HLB can limit access to domestic and international markets. Understanding

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the etiology, symptomatology, and economic consequences of these diseases is essential for developing effective management strategies and sustaining acid lime production in vulnerable agro-climatic zones.

Bacterial Canker

Symptoms: Canker is the most devastating disease. The disease causes tremendous losses

Leaf Lesions

- ✓ Canker lesions are evident on the leaves' underside, and then on the upper surface, about 7-10 days after infection.
- ✓ With the elevated margin and sunken middle, the pustules are corky.
- ✓ The yellow halo around it is a common symptom of the disease on the leaves.

Fig. 1: Canker on leaves

Fruit and Stem Lesions

- ✓ In fruit and roots, citrus canker lesions range up to 1 mm in size and are close to those on leaves.
- ✓ Crop deficiency results in the premature fall of the crop.
- ✓ Usually, the fruit's internal quality is not affected but individual lesions penetrate the rind deeply enough to expose the fruit's interior to secondary microorganism infection.
- ✓ Stem lesions allow the bacteria to live in the long term.

Fig. 2: Canker symptoms on fruit

Casual Organism: *Xanthomonas campestris* pv. *citri*

Bacteria grow on leaves, stems, and fruit in lesions. The bacteria ooze out when free moisture is present on the lesions. Rain splash is the principal dispersal agent and wind helps to penetrate bacteria through natural openings or wounds created by thorns, pruning and insects (leaf miner). Bacterial death increases when exposed to direct sunlight. These bacteria can live in infected tissues of plants that have been kept dry and free from the soil for years (Gohel *et al*., 2022).

Favourable Conditions

- ✓ Wind-driven rain
- ✓ Warm weather
- ✓ High precipitation and high mean temperature
- ✓ Leaf miner infestation

Management

- ✓ Complete eradication of infected trees.
- ✓ Prune out the contaminated branches with pruning scissors
- ✓ Fallen infected leaves and twigs should be gathered and burned.
- ✓ Use tolerant variety eg. Sai Sharbati.

- ✓ Spray copper sulphate 47.15% + mancozeb 30% WDG @ 5 g litre^{-1} of water in June after pruning.
- ✓ Spray Streptocycline (streptomycin sulphate 90% + tetracycline hydrochloride 10%) SP 50 to 100 ppm (50-100 mg litre^{-1} of water) solution repeated interval of 15 to 20 days after the appearance of new growth. Cover the foliage and young fruits fully.

Gummosis

Symptoms

- ✓ Large patches of water-soaked lesions near ground level on the basal portions of the stem.
- ✓ Bark of stem/trunk showed symptoms in lengthwise vertical strips such as dries, shrinks, cracks and shreds.
- ✓ Stem/trunk bark profuse later stage gum exudation.

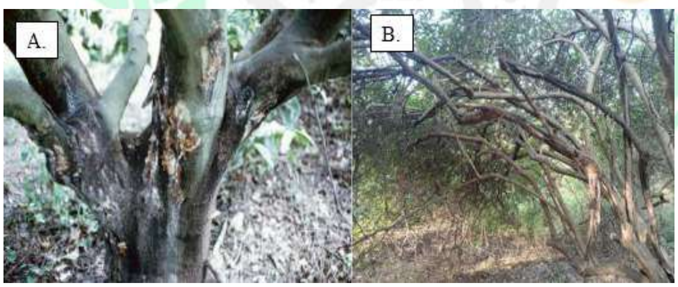

Fig. 3: (A). Severe gummosis and (B). Death of entire tree

Causal organism: *Phytophthora parasitica, P. palmivora, P. citrophthora*

Phytophthora species are spread via soil, nursery stock, irrigation water, and infected roots. In irrigated citrus, runoff can carry the pathogen into water bodies, contaminating new areas. Farm machinery may introduce it to soil, though seeds from infected fruits rarely transmit the disease (Graham and Menge, 1999).

Favourable Conditions

- ✓ High soil moisture.
- ✓ Poor drainage and soil pH between 6.0-6.5.

Management

Preventive Measures

- ✓ Selecting of field for planting of citrus fruits with well-developed drainage system for water.
- ✓ Citrus plant must be planted with little higher than the ground level.
- ✓ Avoiding excess irrigations.
- ✓ Range of planting material (30-45 cm or above) with large budded grafts.
- ✓ Prevent mechanical damage to the crown roots of citrus trees or stem base during cultural activities.
- ✓ To propagate popular/commercial varieties, use resistant sour orange or trifoliate orange rootstock.
- ✓ Apply *Trichoderma viride* multiplied on neem cake (Gohel *et al*., 2022).

Curative Measures

- ✓ Scrape/chisel the sick part out.
- ✓ Spray aureofungin 46.15% w/v SP @ 10 g l^{-1} or metalaxyl M 3.3% + chlorothalonil 33.1% SC @ 2 ml l^{-1} or cymoxanil 8% + mancozeb 64% WP @ 2.5 g l^{-1} of water.

Citrus Tristeza

Symptoms: Infected citrus trees exhibit various symptoms:

Slow decline: Characterized by small leaves, yellowing, twig dieback and reduced fruit.

Quick Decline: Trees wilt and die within weeks, oft en showing minimal symptoms at the graft union.

Fig. 4. Stem pitting

Stem Pitting (Honeycombing): A fine pitting of the inner side of the bark in the portion of the trunk under the bud union.

Stunted trees bloom heavily but gives fewer fruits.

Causal Organism: *Citrus tristeza virus* (CTV)

Survival and Spread

- ✓ CTV is primarily transmitted by brown citrus ap hid (*Toxoptera citricida*).
- ✓ The virus can also spread through grafting and budding infected plant material.
- ✓ Long distance dissemination occurs through the movement of infected citrus planting material.

Management

- ✓ Use of resistant rootstocks.
- ✓ Implement strict quarantine legislation.
- ✓ Use tolerant variety eg. Sai Sharbati.
- ✓ Destroy all diseased trees.
- ✓ Spray chlorpyrifos 20 % EC @ 1 ml l^{-1} of water.

Citrus greening (Huanglongbing)

Symptoms

Infected citrus trees exhibit range of symptoms including:

Yellowing of leaves: Leaves may show asymmetrical yellowing around the veins which can be mistaken for nutrient deficiency.

Mottled leaves: New leaves may emerge small with yellow mottling or blotching.

Irregular fruit: Fruits produced by infected trees are often small, lopsided and bitter with a thick pale peel that remains green at the bottom.

Fig. 5: Irregular fruit

Decline in vigour: Affected trees may exhibit stunted growth, premature defoliation and dieback of twigs, ultimately leading to the death of the tree.

Causal Organism: Candidatus *Liberibacter asiaticus*

Survival and Spread

Spread by the Asian citrus psyllid (*Diaphorina citri*)

Fig. 6: Asian citrus psyllid (*Diaphorina citri*)

Management

- ✓ Control psyllids with insecticides.
- ✓ Use healthy bud wood for propagation.
- ✓ Spray cyantraniliprole 10.26 % OD @ 1.2 ml l^{-1} or imidacloprid 17.80 % SL @ 0.03 ml l^{-1} or

spirotetramat 15.31 % w/w OD @ 0.6 ml l^{-1} or thiamethoxam 25 % WG @ 0.1 g l^{-1} of water (Apply first spray during initial appearance of pest and repeat 2-3 sprays at 15-21 days interval depending on the level of pest intensity).

Conclusion

Acid lime cultivation holds immense economic and nutritional value in India, particularly in Maharashtra, where production continues to rise steadily. However, the sustainability of this growth is threatened by a suite of destructive diseases *viz*. citrus canker, gummosis, tristeza, and Huanglong-bing, that compromise both yield and fruit quality. These diseases, caused by diverse pathogens and spread through vectors, infected plant material, and environmental factors, demand vigilant monitoring and integrated management. Effective disease control hinges on early diagnosis, adoption of resistant rootstocks, strict sanitation, and timely chemical interventions. Moreover, awareness among growers and extension workers about symptom-atology, favourable conditions, and quarantine protocols is crucial to prevent large-scale outbreaks. Strengthening disease surveillance, promoting clean nursery practices, and investing in farmer education will be key to safeguarding acid lime orchards and ensuring the long-term viability of citrus production in India's vulnerable agro-climatic zones.

Note: All chemical pesticides are recommended from CIBRC (Central Insecticide Broad and Registration Committee) approved list.

References

Anonymous. (2025). Production: horticulture crops: fruits: citrus: lime or lemon: Maharashtra economic indicators (CICH). https://www.ceicdata.com/en/india/ production-of-horticulture-crops-in-major-states-fruits-citrus-lime-olemon/production-horticulture-crops-fruits-citrus-lime-or- lemon-maharashtra.

Gohel N. M., Prajapati B. K., and Srivastava J. N. (2022) Major diseases of citrus and their management. Diseases of Horticultural Crops: Diagnosis and Management. Volume 1: Fruit Crops. CRC Press, Taylor and Franscis Group. pp 155-167.

Graham, J. H. and Menge, J. A. (1999). Root diseases. In: Citrus health management. (eds. Timmer, L.W. and Duncan, L.W.) American Phytopathological Society, St. Paul, MN. pp. 126-135.

CIBRC List of Major Uses of Pesticides (Insecticides) as on 31.03.2025. https://ppqs.gov.in/sites/default/files/1._mup_insecticide_03.04.2025.pdf

CIBRC List of Major Uses of Pesticides (Fungicides) as on 31.03.2025. https://ppqs.gov.in/sites/default/files/2._chemical_mup_as_on_31.03.2025.pdf

Present Scenario of Indian Farmers: Challenges, Progress and the Way Forward

Ashish Kumar, Pankaj Singh and Kumar Anshuman

Introduction

India is an agricultural country. India is six largest economies in the world (Normal GDP) having the highest number of employees in the agricultural sector. According to farm output, India is ranked second in the world. According to the Economic survey 2013-14 about 54.6% people in India depend on agriculture and allied sectors for their livelihood. The agriculture sector has bad an annual growth rate of 4.2% in the last five years. But this growth rate is very low. Compare to other developing countries. Indian farmers economic is very low. So they are not able to have proper food, better health facilities, and higher education. In this stage need of modern agriculture. But the Indian farmers are not able to accustom because of their lack of education. So, some of the farmers are choosing the way of suicide. Every single year, through their low income. The national crime records Bureau, data shows that while 2,96,438.00 farmers had died by suicide between 1995 and 2014, in the nine years between 2014-2022, the number stood at 1,00,474.00 Approximately 30 suicides every day. Form the year of 1990 to present the Rampant phenomena of suicide of Indian farmers are very much predominant. Almost near about 11.2% year farmers have been accounted for suicide. Other occupants, are changing their subsistence drastically but due to the rudderless condition of the Indian farmers, the cultivated area is becoming waste land, Total geographical area of India is 328.74 million hectors. The total waste land is 68.85% as reported in 2004. There are 60% of agricultural area in India as reported in the year 2015.

Different problem of Indian Farmers

About two- thirds of Indian's population depends on agriculture. There is a lack of Industry in India. So maximum, people depend on agriculture so, there is heavy pressure on agricultural land. Agriculture plays a central role in the rural economy, but Indian farmers is per capita income is very low, because Indian farmers have very low land holding capacity. And population is high. This reason Indian farmer's per capita income is low. In 2016, the Indian government promised farmers that their income would be doubled by 2022, But it was not given much attention. Indian farmers totally depended on agriculture. Farmers have no other source of income. Lack of technical knowledge is a major problem in

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the Indian farmers. Due to this lack, farmers practice old and less effective method of farming resulting in low productivity. Indian farmers are largely dependent on nature. Rain, soil and natural disasters dramatically impact their crops and income. That is reason Indian farmers have to take loons. Studies dated 2004 through 2006, identified several causes for farmers suicide, such as risky credit system, the difficulty of farming semi arid regions, poor agricultural income, absence of alternative income opportunities, a down turn in the urban economy which forced non-farmers into farming, and the absence of suitable counseling services.

Minimum support price (MSP)

Government every year fixes a minimum support price for major crops grown to support farmers, however, farming community strongly feels that coast of production calculated for the purposes varies from actual cost. Also fixing MSP by government decreases the bargaining power of the farmers.

Climate Changes: The most deliberated issue is global warming and climate change. The climate change has adversely affected Indian agriculture and farmers, as Indian agriculture is heavily dependent on monsoon for irrigation. Due to climate changes and irregular rainfall, irrigation is affected, resulting in field deviation.

Government Economic Policy: Economists like Utsa Patnaik, Jayati Ghosh and Prabhat Patnaik suggest that structural changes in the macro economic policy of the Indian government that favo-red privatization, liberalization and global-ization are the root cause of farmers suicides.

Misdirection of government subsidies and funds: Reports by the central government and NCRB, government farming subsidies from 1993 to 2018 mostly went to producers and dealers, and not to farmers. In 2017, As 35,000 corers of loans and subsidies were given to entities in the cities of New Delhi and Chandigarh, cities that do not have any farmers. Same, in Maharashtra, 60% of government loans and subsidies were given to people and entities residing in Mumbai. This has resulted in money being circulated between the government, banks large and small corporations and politicians, without any of it reaching farmers, aggravating their woes.

Suicidal Ideas: Economist Patel found that southern Indian states have ten times higher rates of suicides than some northern states. This difference, they say, is not because of misclassification of a person's death. The most common cause of suicide in South India is a combination of social issues, such as interpersonal and family problems, financial difficulties and pre exiting mental illness.

Statistics of farmers suicide: National crime records Bureau of India reported in its 2012 annual report that 1,35,445.00 people died by suicide in India, of which 13,755 were farmers (11.2%) of these 5 out of 29 states accounted for 10,486 farmers suicides (76%) Maharashtra, Andhra Pradesh, Karnataka, Madhya Pradesh and Kerala. In 2012, the state of Maharashtra, with 3,786 farmer suicides, accounted for about a quarter of the all India's farmers suicides total (13,754). 2009 to 2016, a total of 25,613 farmers died by suicide in the state. In 2012, there were 745 farmer's suicides in Uttar Pradesh. According to an IFFRI study, the number of suicides from 2005 to 2009 were 387, 905, 75 and 26 in Gujarat, Kerala, Punjab and Tamil Nadu. 1802 farmers died by suicide in Chhattisgarh in 2009 and 1126 in 2010. National crime records Bureau, the number of suicides by farmers and farm laborers increased to 12,360 in 2014, against 11,772 in 2013.

Effects on the country: Indian farmers backbone of the country. But maximum Indian farmers live below the poverty line. So Indian farmers per capita income is very low, So they are not enjoying better life, better education and good health facilities. In 2011, Total population of India 121 crore. Use of large amount of food material.

This leads to deficit in coming of foreign currency, which leave a very bad remark on Indian economic Balance. Indian farmers produce less amount of food grains, but consume high quantity of food grains, so Indian government import food grains resulting a great loss for the nation.

How to manage of this problem

Main problem of farmers are lack of knowledge and education. So duty of the government is to improve their education and knowledge. The government should provide easy access to loans to farmers so that they can buy the resources required for their farming and increase their income. The government has taken steps to make institutional loans easily available to farmers through the (KCC) Kisan Credit Card. The government should provide subsidy to farmers on agricultural equipment and agricultural resources. This is an important help for farmers as it will help them to use modern agricultural technology and resources, which will increase their yield and they will be able to earn more profit. The Pradhan Mantri Kisan Samman Niddi (PM-Kisan), a central sector scheme, aims at providing financial assistance to all cultivate landholding farmers families across the country, subject to certain exclusion criteria. Under the scheme, an amount of Rs. 6000/- is transferred annually in three equal installments of Rs. 2000/- directly into the Aadhar seeded bank accounts of the farmers.

Conclusion

India is an agricultural country. The agriculture sector contributes around 18.3% to India's GDP at current prices. Indian farmers not use modern agriculture and Technology so less production. Maximum farmers being small and marginal, economy of scale is not implemented resulting in higher cost and lower margins. Major concerns of marketing of agricultural produce and fetching good price is very well taken care in contract farming. With the existing marketing structure, margins are distributed among intermediaries leaving meager profit for farmers. The major problems confronting agricultural sector at the moment are a knowledge gap and an infrastructural gap, particularly in rural regions. Farmers get more income when they sell their property to developers, shopping complexes, and manufacturing plants-This has increased the strain on agriculture, necessitating the development of technology to improve productivity in order for India's dwindling farm land to continue to feed its billion plus population in the year to come. The planning commission and government is trying to improve the condition of the farmers. Hence, All Indian Radio airs a programe, for the farmers, named, Krishi Kather Ashar.

References

https://www.icor.org.in

India Brand Equity Foundation (IBEF) (2021). Indian Agriculture and allied Industries report.

Kaushal, G. (2016). Economic History of India 2016, Kalyani Publishers, Ludhiana.

Agriculture Census, Government of India, http://Agcensus.nic.in

Situation of Farmer's Agriculture in India, Siva Bharat, October 27, 2016, Linkedin.

Kaur, N., Singh, E. H. AND Singh, J. (2001). Impact of three farm bills on agricultural during COVID-19 in India.

Murphy, S. (2010). Changing, Perspecting: Small scale farmers, markets and globalization. International Institute for environment and Development (UK) and Hivos (Netherland)

Poor Condition of farmers in India, Vikash Pathak Dec 26, 2013.

Mandelbaum and Devid, G. (2016). Society in India, 2016, Popular Prakashn, Mumbai.

Thorat, S. (2009). Economic Exclusion and Poverty linkages. A reflection on concept, Consequences, and remedies in an Asian context. About IFPRI and the 2020 vision initiative, 421.

Economic Dimensions of Agricultural Supply Chain Inefficiencies in India

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Abstract

India's agricultural supply chain is critical to national food security, farmer welfare, and rural livelihoods. However, the system is marred by inefficiencies that result in significant post-harvest losses, poor price realization for farmers, and high consumer prices. This article analyses the economic dimensions of these inefficiencies through the lens of agricultural economics. It examines factors such as price transmission gaps, logistics bottlenecks, market structure limitations, and policy inadequacies that constrain the performance of India's agricultural supply chain.

Introduction

Agriculture continues to be the backbone of India's rural economy, employing about 42.6% of the workforce while contributing only 18.4% to the country's Gross Value Added (MoAFW, 2023). Despite being a leading producer of cereals, pulses, fruits, and vegetables, the Indian agriculture sector struggles with inefficiencies in its supply chain. These inefficiencies not only reduce the profitability of farming but also distort price signals, lower consumer welfare, and hinder agri-food system modernization.

Theoretical Foundation: Agricultural Supply Chain Economics

From an agricultural economics perspective, a supply chain is more than a logistical arrangement it is a flow of goods, services, information, and value. Efficient supply chains are characterized by:

- ✓ Minimum transaction costs
- ✓ Efficient price transmission
- ✓ Low information asymmetry
- ✓ Optimal allocation of resources
- ✓ High value realization for producers and consumers

In the Indian context, many of these economic ideals are not achieved, leading to systemic inefficiencies and welfare losses.

Major Inefficiencies in the Agricultural Supply Chain

Price Transmission Inefficiency: A core economic concern is the weak transmission of market prices from consumers to producers. Farmers often receive only 25%-40% of the final retail price (Acharya, 2006). This weakens price incentives, reducing

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investment and productivity in agriculture.

High Post-Harvest Losses: According to ICAR-CIPHET (2022), India loses over ₹92,000 crore annually due to post-harvest losses, particularly in perishable crops like tomato, onion, and potato. These losses are due to lack of cold chains, improper packaging, and delayed transportation.

Market Intermediation and Oligopoly: The prevalence of unregulated intermediaries, especially in fruits and vegetables, skews market efficiency. APMC market structures often allow a few traders to control the market, leading to oligopoly-like conditions and price manipulation.

Fragmented Logistics and Infrastructure: Logistics costs in Indian agriculture are 3-4% higher than global averages. Small landholdings, rural road connectivity issues, and a lack of aggregation infrastructure hinder the movement of produce at low cost.

Limited Value Addition: Agricultural economics emphasizes value creation through processing, branding, and quality differentiation. However, in India, only 10% of produce is processed, compared to 65-80% in developed countries (FICCI, 2020).

Economic Consequences of Supply Chain Inefficiencies

Reduced Farm Incomes: Inefficiencies result in a low share of final value reaching the farmer. In crops like tomato and banana, the farmer's share may be as low as 25%.

Volatile Consumer Prices: Supply chain disruptions translate into price spikes for consumers, as seen during onion price surges, despite no corresponding benefit to farmers.

Welfare Loss and Market Failure: In economic terms, these inefficiencies represent deadweight losses and market failures, where the actual market outcome is far from the socially optimal allocation of resources.

Regional Disparities: Well-connected regions benefit from better prices due to access to markets, while remote areas suffer from geographical disadvantages, deepening income inequality.

Policy Responses and Limitations

APMC Reform and e-NAM: The National Agricultural Market (e-NAM) was introduced to integrate APMC markets digitally. However, studies show that many e-NAM markets are only partially functional and suffer from connectivity and adoption issues (Chand, 2020).

FPO Promotion: Farmer Producer Organizations (FPOs) are promoted to increase scale and bargaining power. But only 30% of registered FPOs are operational due to weak governance, low capital, and limited market access (NABARD, 2021).

PM FME and Agri Infrastructure Fund: Recent schemes target the development of cold chains and processing units. However, the lack of coordination among stakeholders continues to delay implementation.

Recommendations from an Economic Standpoint

Strengthen Market Linkages: Support digital infrastructure for rural markets and enable real-time price discovery.

Enhance Storage and Cold Chain Investment: Use PPP models for building economically viable infrastructure.

Improve Institutional Efficiency: Reform the APMC structure to enable more competition and transparency.

Promote Localized Value Chains: Encourage decentralized processing units to reduce perishability-related losses.

Empower FPOs with Working Capital and Training: Economic support must go beyond registration to ensure functional autonomy.

Conclusion

The inefficiencies in India's agricultural supply chain represent both an economic challenge and an opportunity. From price spread distortions to logistical fragmentation, each inefficiency leads to a misallocation of resources and a reduction in economic welfare. A comprehensive agricultural economics approach incorporating infrastructure investment, policy reform, and market intelligence is essential to unlock the full potential of Indian agriculture.

References

Acharya, S. S. (2006). Agricultural marketing and rural credit for strengthening Indian agriculture. New Delhi: Indian Agricultural Research Institute.

NABARD. (2021). Status of Farmer Producer Organizations in India: A Study Report. National Bank for Agriculture and Rural Development.

Chand, R. (2020). e-NAM and APMC Reforms: Issues and Prospects. NITI Aayog Working Paper.

FICCI. (2020). Boosting Agro-Processing in India: Challenges and Opportunities. Federation of Indian Chambers of Commerce & Industry.

ICAR-CIPHET. (2022). Post-Harvest Loss Assessment of Major Crops and Commodities in India. Ludhiana: Central Institute of Post-Harvest Engineering and Technology.

Ministry of Agriculture & Farmers Welfare. (2023). Annual Report 2022-23. Government of India.

Maintenance of Breeder's Seed for Genetic Purity and Seed Security

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Abstract

The production and maintenance of breeder's seed play a critical role in ensuring the genetic purity and long-term availability of crop varieties. This paper outlines essential protocols for harvesting breeder's stock, maintaining genetic purity in established varieties through isolation and bulk selection methods, and the importance of carry-over seed in safeguarding against seed loss. By following rigorous seed handling practices, breeders can uphold seed quality and ensure the success of foundation and certified seed programs.

Introduction

Breeder's seed is the initial and most genetically pure seed class in the formal seed production chain. It serves as the foundation for producing foundation and certified seeds, which are distributed to farmers. Therefore, maintaining the genetic purity and quality of breeder's seed is essential to preserve the integrity of crop varieties. This article discusses the standard practices for harvesting breeder's stock, maintaining breeder's seed purity, and securing seed availability through carry over strategies.

Harvesting the Breeder's Stock: Harvesting breeder's stock requires meticulous attention to prevent genetic contamination. All equipments used like threshers, seed containers, bags, and handling tools must be thoroughly cleaned to remove any residues of previous seed lots or other crop varieties. This practice ensures that the harvested breeder's seed achieves approximately 99.9% varietal purity. Once harvested and cleaned properly, the seed is prepared for multiplication into foundation seed.

Maintenance of Breeder's Seed of Established Variety

Two effective methods are employed

Isolation and Rigorous Rouging: The breeder's seed should be grown in isolated plots to avoid cross-pollination with other varieties. Rigorous rouging must be conducted at various growth stages to eliminate off-type or deviant plants based on observable characteristics such as plant height, leaf shape, maturity, and other varietal traits.

Bulk Selection: For improving or stabilizing the genetic purity of established varieties, bulk selection is a reliable method. This involves selecting 2,000 to 2,500 plants that are true to type. These plants are

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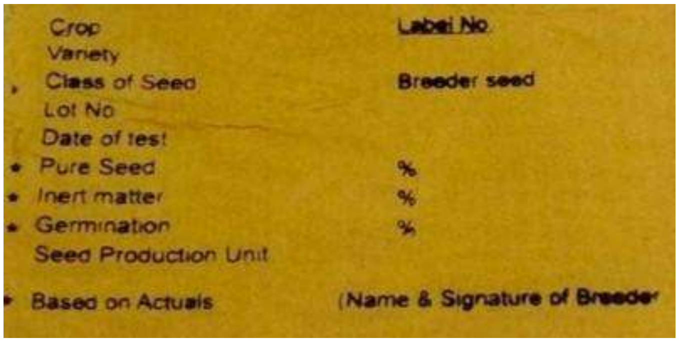
harvested individually and threshed separately, after which the seeds are bulked. This process helps preserve the uniformity and desirable traits of the variety.



Breeder seed label

Carry-over Seed and Variety Security: Carry-over seed refers to a strategic reserve of breeder's seed maintained by the breeder to mitigate risks of seed loss due to environmental, production, or logistical failures during foundation seed multiplication. It is recommended that breeders retain enough seed stock to cover at least one season's requirements. Additionally, a portion of the originally released breeder's seed should be preserved under ideal storage conditions like cool, dry, and pest free to ensure its viability and integrity over time. This acts as a genetic backup and ensures the long-term availability of the variety.

Conclusion

The integrity of crop varieties begins with the breeder's seed. Proper harvesting, careful maintenance, and secure storage of breeder's seed are essential to ensure varietal purity and continuity in seed production systems. By adopting best practices such as equipment sanitation, isolation, rigorous rouging, bulk selection, and carry-over storage, breeders play a pivotal role in preserving the genetic quality and availability of crop varieties. These efforts contribute significantly to the success of national seed programs and sustainable agricultural development.

References

Sahoo, J. P. (2020). Maintenance of seed purity nucleus and breeder seed production. Agri mirror: Future India PP-40-44

Sharma, K. D. (2022). Principles of quality seed Production. In Seed Science and Technology PP-123-145. Springer.

Factors Responsible for Genetic Purity

M. Sarmila, S. Subhashini and K. Chozhan

Abstract

Genetic purity is a critical cornerstone in crop production, ensuring that seeds maintain their original genetic identity and there by sustain consistent yield and quality. However, several natural and human-driven factors, such as cross pollination, genetic drift, seed mixing during production or storage, and unintended contamination from genetically modified organisms. To address these issues, strategies including physical isolation, genetic testing, seed certification, careful field management and education of stakeholders have been developed and implemented across the agriculture sector. By adopting such practices, the agriculture industry not only safeguards the integrity of crop varieties but also secures food reliability and sustainability for future generation.

Introduction

Genetic purity refers to the trueness of a plant variety to its type, indicating the absence of any genetic contamination from other varieties or species. This quality is essential in agriculture, particularly in seed production, as it ensures that the desirable traits of a crop such as yield, disease resistance and grain quality are consistently passed on to future generation. However, maintaining genetic purity is a complex process influenced by various biological, environmental and human factors

Key factor responsible for genetic purity

Developmental variations

- ✓ Growing crops outside their adapted environmental such as different soils, climates, or elevation can cause developmental shifts, leading to changes in plant characteristics and gradual deterioration of genetic purity.
- ✓ To minimize such variation, it is important to cultivate varieties in regions that closely match their original adaption zones.

Mechanical mixtures

- ✓ Mechanical mixtures are one of the most significant threads to genetic purity. These occurs when seeds of different varieties are mixed at any stage, from sowing to harvesting to storage
- ✓ Common source includes:
  - Using the same machinery for different varieties without through cleaning.
  - Growing adjacent fields with different varieties.

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- Contaminated storage facilities or packaging materials

- ✓ Vigilant seed field inspection and rigorous cleaning protocols are essential to avoid these risk

Natural crossing (cross-pollination)

- ✓ Natural crossing refers to the unintended transfer of pollen between different plant varieties, especially in cross pollinated species.
- ✓ Isolation and buffer zones are standard methods to reduce cross-pollination.

Mutation and minor genetic variation

- ✓ Minor genetic variations may accumulate over multiple generations even under controlled conditions, contributing to gradual genetic drift and potential loss of varietal purity.

Seed production and handling errors

- ✓ Mixing seeds during harvesting, cleaning or storage can easily contaminate genetically pure seed lots.
- ✓ Contamination can also occur due to volunteer plants from previous crops or improper packaging.

Pest and disease pressure

- ✓ Outbreaks of pest or disease can exert selective pressure, leading to inadvertent selection for certain genotypes and shifts away from the original variety characteristics.
- ✓ Introduction of pest or disease resistance genes from other varieties can also impact purity if not managed carefully.

Influence of plant breeders techniques

- ✓ Techniques used by plant breeders during variety development or seed multiplication play a crucial role.
- ✓ Inadequate selection methods or the use inappropriate breeding material may contribute to the loss of genetic identity in a variety.

Genetic modification and biotechnological interventions

- ✓ As genetically modified (GMO) crops become more prevalent, the risk of unintentional GMO contamination in non GMO seed lots is a growing challenge.
- ✓ Strict genetic testing and seed certification are necessary when GM and non GM crop coexist.

Conclusion

The genetic purity of crop varieties is not only a matter of agricultural productivity but also supports farmer's livelihoods, market standards, and food security. Marinating this purity is a multifaceted challenge requiring vigilance at every step from breeding to final seed distribution. Through careful field management, isolation, testing and certification, genetic purity can be preserved across generation and production cycles, ensuring the sustainability of high quality crop varieties

References

Sendekie, Y. (2020). Review on; Seed Genetic Purity for Quality Seed Production. *International Journal of Scientific Engineering and Science*, 4(10): 2020.

Genetic Purity an overview. *Science Direct Topics*, accessed 2025.

Bonsai Landscaping

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Abstract

Bonsai, originating from the Japanese words *bon* (tray) and *sai* (planting), is the traditional art of cultivating miniature trees and shrubs in containers to replicate the appearance of mature trees found in nature. This practice combines principles of horticulture, aesthetics, and plant physiology. The main techniques employed in bonsai creation include pruning, wiring, defoliation, root trimming, and controlled irrigation and nutrition, which collectively regulate plant growth and form. Suitable plant species for bonsai include *Ficus retusa*, *Juniperus procumbens*, *Carmona retusa*, and *Bougainvillea glabra*, chosen for their adaptability, small foliage, and tolerance to frequent pruning. The growing medium plays a vital role in bonsai maintenance, requiring proper aeration, drainage, and nutrient availability to support root health within confined spaces. In contemporary landscaping, bonsai serves not only as an ornamental art form but also as a sustainable greening solution, promoting aesthetic harmony, mental well-being, and appreciation of nature within urban environments. This review emphasizes the importance of bonsai in modern horticulture and landscaping, highlighting its potential for enhancing interior and exterior spaces while fostering environmental mindfulness and artistic expression.

Introduction

Bonsai, derived from the Japanese words *bon* (tray) and *sai* (planting), refers to the artistic practice of cultivating miniature trees in containers that resemble mature trees found in nature (Naka, 1990). The art of bonsai originated in China as *Penjing* over a thousand years ago and was later refined in Japan into a disciplined horticultural and aesthetic tradition (Kumar and Bhat, 2017). It integrates both scientific and artistic principles, requiring knowledge of plant physiology, pruning, wiring, and root management to maintain plant vigour and desired form (Hartmann *et al.*, 2018). Species such as *Ficus retusa*, *Juniperus procumbens*, *Carmona retusa*, and *Bougainvillea glabra* are commonly used due to their adaptability to containerized environments and tolerance to frequent pruning (Singh and Chauhan, 2020). In addition to being an art form, bonsai contributes to modern landscaping by enhancing visual appeal, promoting biophilic design and providing psycho-logical and environmental benefits in urban spaces (Li and Wang, 2019). The practice encourages sustainable horticultural methods and fosters a deeper appreciation of nature's balance and beauty

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(Chen *et al.*, 2005). Examples: *Ficus retusa*, *Juniperus procumbens*, *Carmona retusa*, and *Bougainvillea glabra*, and *Punica sps*.

Types of Bonsai styles

There are many styles in bonsai, which have been developing over the ages. The following are the principal classical bonsai styles.

Formal upright style/ Chokkan style: In this style branches grow symmetrically and horizontally around the upright straight trunk.

Winding /Curved trunk style/ kyokkuk style: In this style plants retain a very natural appearance with the help of curving nature of the trunk. The branches get smaller in size towards the top growing also in the edge of the curves.

Oblique/Leaning trunk style/Shakan style: The trunk leans to one side, branches are positioned horizontally, shooting out in all directions. The surface roots clearly visible in the side opposite to lean.

Windswept style: Gives the impression of the blowing continually from the direction.

Broom style: This style having the similarity in appearance to unturned broom. It spreads the branches in the shape of a fan, may occupy half the total height of the tree. The trunk is upright

Cascade style/Kengai Style: The branches grow out over the edge of the container chosed fothis style is high enough to show off cascade effect to best advantage

Multiple trunks style or clump shaped: Trunks are allowed to grow a single root, which has put several shoots. The result of this is a little group of trees. Generally, they should make up an odd number but if only trunks appear, they should of different sizes.

Raft style: This style creates an effect of fallen trunk, which has put out roots downward, and branches upward. The final impression, which is quite original, is one of the groups of individual plants all spring from a horizontal trunk

Woodland: In this fascinating style, in a single container a number of all individual plants of the same species are laid out in a correctly proportioned manner.

Twisted trunk style: The trunk diminishes size toward the top and gives the appearance of twisting in upon itself; the branches break out in all directions.

On the rock: The piece of rock is placed appropriately in the container to be embraced eventually by the roots of the bonsai. This however sinks into the soil below. Once the little tree starts growing and putting new roots in to small cavities in the rock, one can get so called "rock planting".

Pots or containers for bonsai

- ✓ The pots and containers used for bonsai vary in material, shape and size.
- ✓ Small ceramic or terracotta pots and containers of square, rectangular, oval or round shape are the best for bonsai.
- ✓ Sometimes small cement containers are also utilized for this purpose but these are not convenient to handle because of their heavy weight.
- ✓ The choice of the shape and colour of the container depends upon the style and the type of plant used for bonsai.
- ✓ Usually, terracotta and light colours are preferable. The rectangular and oval shaped containers are ideal for most of the bonsai styles.
- ✓ The round or square container is suitable for growing a single plant in its centre unlike the other shapes in which the plant is placed on one side of the container.

Conclusion

Bonsai represents a perfect blend of art and science, demonstrating how careful cultivation and aesthetic vision can transform ordinary plants into living masterpieces. It emphasizes harmony between nature and human creativity through techniques like pruning, wiring, and root trimming. The practice not only enhances ornamental and landscape value but also promotes patience, mindfulness and environmental appreciation. With proper species selection and management, bonsai can thrive for decades, symbolizing balance and endurance. In modern landscaping, it serves as a sustainable decorative element for both indoor and outdoor spaces. Overall, bonsai continues to inspire global admiration as a timeless expression of horticultural artistry.

References

Chen, J., McConnell, D. B. and Henny, R. J. (2005). Cultural Guidelines for Commercial Production of Interiorscape Ficus. *University of Florida IFAS Extension Bulletin ENH 979.*

Singh, A. and Chauhan, R. (2020). “Bonsai and Its Role in Modern Landscaping. *Journal of Ornamental Horticulture*, 23(2): 65-71.

Hartmann, H. T., Kester, D. E., Davies, F. T. and Geneve, R. L. (2018). *Plant Propagation: Principles and Practices.* 9th ed. Pearson Education.

Kumar, R. and Bhat, Z. A. (2017). Bonsai: An Ancient Art of Miniaturization of Plants. *International Journal of Pure & Applied Bioscience,* 5(6): 1428-1433.

Li, X. and Wang, Y. (2019). Containerized Tree Growth and Root Management in Urban Landscaping. *Urban Forestry & Urban Greening,* 39: 154-163.

Naka, J. (1990). *Bonsai Techniques II.* Bonsai Institute of California.

Seed Coating with Biofertilizer and Biopesticides

S. Yazhini, S. Subashini and K. Chozhan

Abstract

Seed coating with biofertilizers and biopesticides is an advanced technique in seed enhancement that improves seed performance, crop productivity, and sustainability. It provides a protective and nutritive layer around the seed, enabling early germination, better nutrient uptake, and resistance against soil-borne pathogens. This eco-friendly approach reduces the dependency on chemical fertilizers and pesticides, promoting sustainable agriculture.

Introduction

Seed coating is the process of applying biological, physical, or chemical materials onto the seed surface to enhance its performance. The integration of biofertilizers and biopesticides in seed coating technology ensures a balanced approach toward crop nutrition and protection. Unlike traditional seed treatments using synthetic chemicals, bio-based coatings are safe for the environment, non-toxic and enhance soil health. Biofertilizers such as Rhizobium, Azospirillum, Azotobacter, Phosphate Solubilizing Bacteria (PSB), and Arbuscular Mycorrhizal Fungi (AMF) help in nutrient mobilization and nitrogen fixation. Biopesticides like Trichoderma, Pseudomonas fluorescens, and Bacillus subtilis act as antagonists against harmful fungi and bacteria.

Objectives of Seed Coating

- ✓ To improve seed germination and seedling vigor.
- ✓ To enhance nutrient availability and uptake.
- ✓ To protect seeds and seedlings from pathogens and pests.
- ✓ To ensure uniform seed distribution and easy sowing.
- ✓ To reduce the dependency on chemical inputs.

Materials Used for Coating

Adhesive agents: Gum arabic, jaggery solution, CMC (Carboxy Methyl Cellulose), or starch paste.

Fillers: Talc, kaolin clay, lime, charcoal powder.

Active ingredients: Biofertilizers (e.g., Rhizobium, Azotobacter), Biopesticides (e.g., Trichoderma viride, Pseudomonas fluorescens).

Colorants (optional): For seed identification and aesthetic value.

Methods of Seed Coating

Dry Coating: Seeds are mixed with a fine powder of

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bio-agents and adhesive in minimal moisture conditions.

Slurry Coating: A slurry of biofertilizers and biopesticides is prepared with adhesive and mixed with seeds, followed by drying.

Film Coating: A thin polymer film is applied over seeds containing bio-agents, ensuring better adhesion and protection.

Pelleting: Seeds are enlarged into uniform pellets by adding coating materials, suitable for small seeds like onion or carrot.

Mechanism of Action

Biofertilizers fix atmospheric nitrogen, solubilize phosphorus, and mobilize micronutrients, improving soil fertility. Biopesticides suppress pathogens through antibiosis, competition, and induction of plant defense mechanisms. The coating materials also enhance microbial survival on the seed surface until sowing.

Advantages

- ✓ Enhanced seed germination and vigor.
- ✓ Improved plant growth and yield.
- ✓ Protection against soil-borne diseases.
- ✓ Environmentally friendly and sustainable.
- ✓ Cost-effective compared to chemical treatments.

Limitations

- ✓ Short shelf life of coated seeds due to microbial viability loss.
- ✓ Sensitivity to storage conditions (temperature and humidity).
- ✓ Compatibility issues between different microbial strains.

Applications

- ✓ Used in crops like pulses (Rhizobium coating), cereals (Azospirillum), oilseeds (Trichoderma, PSB) and vegetables (Pseudomonas fluorescens).
- ✓ Widely adopted in organic and sustainable farming systems.

Conclusion

Seed coating with biofertilizers and bio-pesticides is an eco-friendly seed enhancement technique that promotes early seedling establishment, nutrient efficiency, and disease resistance. It aligns with the goals of sustainable and low-input agriculture by combining biological inoculants with modern seed treatment technology.

References

Subba Rao, N.S. (2020). Biofertilizers in Agriculture and Forestry. Oxford & IBH Publishing.

Yadav, A. K. *et al*. (2021). Seed coating with bio-inoculants: A step towards sustainable crop production. *Journal of Applied Microbiology* 130(3): 827-839.

FAO. (2022). Biological Seed Treatments for Sustainable Agriculture.

The Microorganism that Caused the Great Famine: Lessons from the Potato Blight

Sonali Routray, R. Arutselvan, Sulekha Pradhan and Kaliprasad Jena

Abstract

The Great Irish Famine (1845-1852), caused by the oomycete *Phytophthora infestans*, decimated Ireland's potato crop, leading to approximately one million deaths and mass emigration. This article examines the biological and socio-economic factors behind this catastrophe, focusing on the pathogenesis of *P. infestans*, its interaction with the susceptible potato (*Solanum tuberosum*), and the environmental conditions that fueled its spread. The pathogen's rapid life cycle, genetic adaptability, and Ireland's reliance on the genetically uniform Irish Lumper variety amplified the crisis, exacerbated by inadequate government responses and monoculture practices. The famine's legacy underscores the dangers of crop uniformity and systemic vulnerabilities. Modern strategies, including molecular detection, integrated pest management, and resistance breeding using genes from wild potato relatives, aim to control *P. infestans* and prevent similar disasters. However, evolving pathogen strains and climate change pose ongoing challenges. By integrating lessons from the famine diversifying crops, strengthening food systems, and aligning science with policy we can enhance global food security and resilience against future agricultural crises.

Introduction

The Great Irish Famine (1845-1852), triggered by the potato blight caused by the microorganism *Phytophthora infestans*, was a catastrophic event that reshaped Ireland's social, economic and demographic landscape. This water mold devastated potato crops, a staple food for millions, leading to widespread starvation, disease, and emigration. Approximately one million people died, and another million emigrated, reducing Ireland's population by nearly a quarter. The famine exposed vulnerabilities in monoculture farming, colonial policies, and inadequate relief efforts, highlighting the interplay between environmental, social, and political factors in agricultural crises. Studying the potato blight offers critical lessons for modern agriculture, emphasizing the need for crop diversity, resilient farming practices, and robust disaster response systems to mitigate the impact of plant pathogens. Understanding *Phytophthora infestans*'s role underscores the importance of scientific advancements in disease management to prevent similar tragedies.

Figure 1: Potato slice showing infection symptoms of bacterial soft rot

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Table 1: Life Cycle of *Phytophthora infestans*

Life Cycle Stage	*P. infestans*	*P. sojae*	Environmental Trigger
Dispersal	Airborne sporangia; motile zoospores	Soil/waterborne zoospores; oospores	Wet, cool (10-25°C) vs. warm, saturated (>20°C)
Infection Site	Leaves, stems, tubers	Roots, stems	Aerial vs. soil entry
Survival	Soil debris (months)	Oospores in soil (5-10 years)	Short-term epidemics vs. long-term persistence
Reproduction	Asexual (clonal); rare sexual	Primarily self-fertile (homothallic); rare outcrossing	Global lineages vs. regional pathotypes

Pathogenesis of *Phytophthora infestans*: Life Cycle and Infection Mechanism

Phytophthora infestans, though often mistaken for a fungus, is an oomycete, a water mold with a complex life cycle. It thrives in cool, moist conditions, spreading via airborne or waterborne sporangia. These spores germinate directly or release motile zoospores that infect potato leaves, stems, and tubers. Once inside the host, the pathogen forms haustoria, structures that extract nutrients, causing rapid tissue necrosis. Within days, infected plants develop dark lesions, and tubers rot into foul-smelling masses. The pathogen's ability to produce millions of spores daily and survive in soil or plant debris makes it highly destructive. In Ireland's damp climate of 1845, these traits enabled *Phytophthora infestans* to spread rapidly, obliterating fields (Ó Gráda, 2009).

Host-Pathogen Interaction: Susceptibility of *Solanum tuberosum*: The potato, *Solanum tuberosum*, was particularly vulnerable to *Phytophthora infestans* due to its genetic uniformity. The Irish Lumper, the dominant variety in Ireland, lacked resistance genes, making it an ideal host. The pathogen exploits the plant's cellular structure, penetrating cell walls and disrupting photosynthesis and nutrient transport. This interaction triggers a cascade of decay, rendering tubers inedible. The reliance on a single variety meant that once the blight took hold, no resistant strains were available to mitigate losses. This monoculture amplified the famine's impact, as farmers had no alternative crops to fall back on (Donnelly, 2001).

Environmental Conditions Favoring Blight Proliferation: *Phytophthora infestans* thrives in wet, cool environments (10-25°C), conditions prevalent in Ireland during the 1840s. Heavy rainfall and high humidity facilitated spore dispersal and germination, while mild temperatures allowed the pathogen to complete its life cycle rapidly. Poor farming practices, such as planting infected tubers, further spread the disease. The absence of crop rotation and limited access to fungicides among impoverished farmers exacerbated the problem. These environmental and cultural factors created a perfect storm, enabling the blight to devastate Ireland's potato crops year after year (Kinealy, 1994).

Genetic Diversity and Evolution of *P. infestans*: *Phytophthora infestans* is a highly adaptable pathogen, capable of evolving to overcome host resistance and chemical controls. Its genetic diversity stems from sexual and asexual reproduction, allowing it to develop new strains with varying virulence. During the famine, a single strain, likely introduced from North America, caused widespread damage. Since then, *P. infestans* has continued to evolve, with modern strains showing resistance to fungicides. This adaptability underscores the need for ongoing research into the pathogen's genomics to predict and counter its evolution. The famine highlighted the risks of genetic uniformity in crops, a lesson that remains critical as new strains emerge globally (Daly, 1993).

Modern Detection, Control, and Resistance Breeding Strategies: Today, managing *Phytophthora infestans* involves advanced detection, chemical controls, and genetic strategies. Early detection relies on molecular techniques like PCR to identify the pathogen in plant tissue before symptoms appear. Fungicides, such as metalaxyl, are widely used, but resistance in some strains has prompted integrated pest management (IPM) approaches. IPM combines chemical treatments with cultural practices like crop rotation and removal of infected debris. Resistance breeding has made significant strides. Scientists have identified resistance genes in wild potato relatives, such as *Solanum demissum*, and incorporated them into commercial varieties. Genetically modified potatoes with stacked resistance genes offer promising results, though public acceptance of GMOs varies. The International Potato Center and other institutions maintain diverse potato germplasm to ensure resilience against evolving pathogens. These strategies, grounded in lessons from the famine, aim to prevent crop failures and protect global food security (Ó Gráda, 2009).

Conclusion

The Great Irish Famine, driven by *Phytophthora infestans*, was a tragedy of biology and human failure. The pathogen's destructive life cycle, the susceptibility of *Solanum tuberosum*, favorable environmental conditions, and the organism's genetic adaptability combined with socio-economic vulnerabilities to create a catastrophe. The famine's legacy mass starvation, emigration, and societal upheaval underscores the dangers of monoculture and inadequate policy responses. Modern advances in detection, control, and resistance breeding offer tools to combat potato blight, but challenges like climate change and pathogen evolution persist. By learning from the past, we can build resilient agricultural systems, ensuring that no population faces the horrors of famine again.

References

Daly, M. E. (1993). Review of the book 'The Visitation of God'? The Potato and the Great Irish Famine. *Irish Economic and Social History*, 20(1): 124-125.

Donnelly, J. S., Jr. (2001). The Great Irish Potato Famine. Stroud, UK: Sutton Publishing Limited.

Kinealy, C. (1994). *This great calamity: The Irish Famine 1845-52*. Gill & Macmillan.

Ó Gráda, C. (2009). *Famine: A short history*. Princeton University Press.

Molecular Diagnostic Techniques & Importance: A New Frontier in Protecting Plants

A. D. S. M. Dharmasena

Introduction

With climate shifts, booming international commerce and rising food needs defending crops against pests and diseases is more important than ever. Relying only on older approaches observing symptoms, using a microscope or growing pathogens (viruses, bacteria, fungi and nematodes) in labs no longer enough and where molecular diagnostics developed. It includes fast, accurate and highly sensitive methods that are transforming how protect plants offering a path toward more resilient and sustainable agriculture. Molecular diagnostics illustrates that detect pests or diseases by using the pathogen's genetic material (DNA or RNA) instead of depending only on visible symptoms or growing the pathogen in laboratory cultures. Those methods are sensitive enough to find pathogens even in very small amounts or before any symptoms show making them crucial for stopping outbreaks early and helps to reduce damage to crops. There are more benefits of this molecular approach and can be describe as follows. It facilitates early detection. Latent infections are a major problem because by the time symptoms show and it's often too late for effective control. Molecular methods can spot pathogens early times. Also it has high specificity and sensitivity. These tests can distinguish between closely related species or strains of pathogens as well as helping ensuring correct treatment. Speed also considerable factor as many molecular techniques provide results far faster than culturing or traditional lab tests. In addition, better surveillance and trade protection is important for some countries can use molecular diagnostics for screening seeds and planting helping prevent the introduction of quarantine pathogens also.

The key strategies to make molecular diagno-stics even more effective are mainly developing portable and field-friendly tools, building capacity**,** integrating diagnostics into broader disease management**,** improving protocols and international standards and continuous research methods are more important. Here are several important molecular diagnostics techniques used (or under development) for plant protection techniques. Conventional PCR (Polymerase Chain Reaction) is the most common and simple method and it amplifies specific DNA sequences of pathogens using thermal cycling. Real-time PCR / Quantitative PCR (qPCR / RT-qPCR) monitor DNA amplification in real time via fluorescent dyes or probes. It quantifies pathogen

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load. In digital PCR (dPCR) technique, the sample is partitioned into many small reactions (droplets or wells) and PCR is run in each partition and this allows absolute quantification of target DNA even at very low concentrations. Further this is very sensitive, but expensive and more technically demanding. For an example In Real-time PCR (qPCR) allows Identification of bacterial blight of rice caused by *Xanthomonas oryzae* pv. oryzae in *Oryza sativa* (rice**).** In isothermal amplification methods amplify DNA (or RNA) at a constant temperature and no thermal cycling is needed. It makes them more suitable for field or simpler setups. LAMP (Loop-Mediated Isothermal Amplification) Works at ~60-65 °C and Uses 4 to 6 primers targeting multiple regions providing high specificity. RT-LAMP (Reverse Transcription LAMP) is used for detecting RNA viruses. RPA (Recombinase Polymerase Amplification) method is done at lower temperatures (~37-42 °C) and frequently used in field diagnostics and in combination with other detection modules. For instance, detection of Citrus greening disease (Huanglongbing) caused by Candidatus *Liberibacterasiaticus* in *Citrus sinensis* (orange) can be examined by LAMP

Another advanced technique is CRISPR-based diagnostics or CRISPR-Cas Biosensors**.** These methods couple nucleic acid amplification (RPA, LAMP) with CRISPR-Cas systems (such as Cas12, Cas13) that can cut or cleave reporter molecules upon recognizing the target sequence. In this method the cleavage triggers a detectable signal (fluorescence, color change, lateral flow strip).Method is highly specific (because of CRISPR guide RNA targeting) and sensitive. Some systems are being engineered for field-deployable use (combining amplification + CRISPR reaction in the same tube).

Next-Generation Sequencing (NGS) is another approach to plant protection. Here, Instead of targeting a single pathogen NGS can sequence all DNA (or RNA) in a sample. It allows detection of known and unknown pathogens, and profiling pathogen communities. This is useful for surveillance, discovering new threats and understanding pathogen diversity of plants. More valuable as more resource-intensive method. Furthermore, Surveyor nuclease assay, hybridization / microarray methods and biosensor platforms / nanotechnology integration are novel advanced methods as molecular techniques to protect plants. For an example for other recently developed methods, a smartphone-integrated RPA-CRISPR-Cas12a system can be used for early detection of potato late blight and using microneedle sampling and fluorescent readouts via phone cameras and it achieved detection rates as very early. Also some molecular tools can detect R genes (resistance genes) in plants helping develop or select resistant crop varieties. For an example using DNA markers can detect resistance of genes against Late blight of potato caused by *Phytophthora infestans* in *Solanum tuberosum* (potato).

These are some of the main limitations of using molecular diagnostics for plant protection. Degradation of RNA (for RNA viruses) can be a problem. RNA is less stable than DNA and if sample handling is not careful RNA might degrade. When pathogens are present in very low amounts molecular tests may struggle to detect them unless very sensitive techniques are used (nested PCR, qPCR or other). Also it might need several rounds of amplification. Some isothermal methods (LAMP) have detection limits that are higher than the best lab methods and detection limit can vary depending on pathogen, sample type and the primer/probe design. Sometimes due to high genetic variability in pathogen populations if the primers/probes are designed based on known strains, they might fail to detect new variants and may be cross reacted with closely related non-target species. Many molecular diagnostic methods require sophisticated lab equipment (thermocyclers, fluorescence detectors and sequencing machines) and skilled staff and controlled environments. These are not always available in field or remote areas. In addition, lack of harmonized protocols, quality control and proficiency testing and standard markers can make comparison between labs or regions difficult.

Molecular diagnostics represent a powerful tool in the plant protection toolbox. They have the potential to reduce crop losses, ensure food security and make agriculture more sustainable in the world. Molecular diagnostic techniques have revolutionized plant protection by enabling early, precise, and sensitive detection of pathogens which is essential for effective disease management and sustainable agriculture. Techniques such as Polymerase Chain Reaction (PCR), Enzyme-Linked Immuno Sorbent Assay (ELISA) and Next-Generation Sequencing (NGS) allow for the identification of pathogens even at low concentrations and before visible symptoms appear, facilitating timely interventions. These methods also support the development of disease-resistant plant varieties and inform the selection of appropriate control measures.

Conclusion

Molecular diagnostics are crucial for detecting and managing regulated plant pathogens at borders and in nurseries, helping to prevent the introduction and spread of invasive species. In summary, molecular diagnostics are indispensable for modern plant protection, preventing disease outbreaks, developing resistant crop varieties, supporting quarantine programs, offering tools for early detection, accurate identification and informed disease management all of which contribute to sustainable agricultural practices and food security.

Unlocking the Insect World: Application of Omics in Entomology

Lipsa Dash, Ipsita Das and Pragyan Paramita Rout

Introduction

Insects are the most diverse and adaptable group of animals on Earth. From pollinators like bees and butterflies to notorious pests like mosquitoes and locusts, they influence agriculture, ecosystems, human health and even global economies. Understanding insects has therefore been at the heart of entomology for centuries. However, conventional approaches such as morphological identification, behavioral studies, and classical genetics often provided only a partial picture of their biology. In recent decades, the rise of omics technologies including genomics, transcriptomics, proteomics, metabolomics, and epigenomics has revolutionized the study of insects. Collectively referred to as "omics," these approaches allow scientists to explore the complex molecular networks that drive insect growth, development, adaptation, and interactions with their environment. Omics is essentially about capturing the "big picture" of biological systems, making it a powerful tool for solving entomological challenges in agriculture, medicine, biodiversity, and conservation.

This article highlights the application of omics in entomology, emphasizing how these cutting-edge technologies are transforming pest management, pollinator health, vector-borne disease control, and ecological research.

The Omics Revolution in Entomology

Omics refers to large-scale approaches that aim to map and analyze the complete set of molecules in living organisms. Each omics field focuses on a specific level of biological information:

Genomics: Study of the complete DNA sequence of an organism.

Transcriptomics: Analysis of RNA transcripts that reflect gene activity.

Proteomics: Profiling of proteins expressed in cells or tissues.

Metabolomics: Identification of small molecules and metabolites involved in physiology.

Epigenomics: Study of heritable changes in gene expression not coded in DNA sequence.

Microbiomics: Eexploration of microbial communities associated with insects.

By combining these approaches (integrative omics), entomologists can move beyond studying single genes or traits to understanding entire biological systems.

Genomics: Decoding the Blueprint of Insects

Genomics has been the cornerstone of modern entomology. With the advent of next-genera-

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tion sequencing (NGS), insect genomes can be sequenced faster and cheaper than ever before.

Pest management: Sequencing of pest genomes like the fall armyworm (Spodoptera frugiperda) or cotton bollworm (Helicoverpa armigera) has revealed genes linked to insecticide resistance. This information helps in designing novel pesticides and monitoring resistance evolution.

Disease vectors: The genomes of mosquitoes (*Anopheles gambiae, Aedes aegypti*) and sandflies have been sequenced to identify genes responsible for transmitting malaria, dengue, and leishmaniasis. Genome editing tools like CRISPR-Cas9, informed by genomic data, are now being used to engineer sterile or resistant mosquito strains for vector control.

Pollinator health: The sequencing of the honeybee (Apis mellifera) genome has provided insights into immunity, social behavior, and responses to environmental stressors, supporting conservation strategies.

Thus, genomics provides the foundational "blueprint" to understand insect biology and apply it to practical challenges.

Transcriptomics: Listening to the Voices of Genes

While genomics tells us what could happen, transcriptomics reveals what is actually happening inside insect cells at a given moment. By sequencing RNA, scientists can study gene expression under different conditions.

Stress and adaptation: Transcriptomic studies have shown how insects respond to heat, drought, or pesticide exposure by switching on or off specific genes. This helps in predicting pest outbreaks under climate change scenarios.

Host–pathogen interactions: In mosquitoes, transcriptomics has revealed how immune genes are activated when they ingest malaria parasites. Such findings pave the way for blocking parasite development inside the insect.

Development and metamorphosis: The transformation of a caterpillar into a butterfly is guided by complex gene expression changes. Transcriptomics maps these changes, giving clues to hormonal control and developmental biology.

By capturing the dynamic "voices" of genes, transcriptomics provides a real-time snapshot of insect physiology.

Proteomics: Mapping the Workhorses of Life

Proteins are the functional molecules that carry out cellular activities. Proteomics, the large-scale study of proteins, helps entomologists understand the biochemical machinery of insects.

Insecticide targets: Proteomic studies identify detoxification enzymes such as cytochrome P450s, esterases, and glutathione-S-transferases that allow insects to survive pesticide exposure.

Venom and saliva analysis: The saliva of mosquitoes or the venom of parasitoid wasps contains proteins that suppress host defenses. Proteomics reveals their structure and function, aiding in medical entomology and drug discovery.

Pollinator nutrition: Proteomic analysis of bee hemolymph (insect blood) and royal jelly has provided information on nutrition and immune health in pollinators, vital for their conservation.

Proteomics therefore connects genes with their biological functions, serving as a bridge between genetic information and observable traits.

Metabolomics: The Chemical Fingerprint of Insects

Metabolomics focuses on small molecules such as amino acids, sugars, lipids, and secondary metabolites. These molecules directly influence insect survival, reproduction, and ecological interactions.

Insect–plant interactions: Metabolomics helps unravel how herbivorous insects detoxify plant toxins or how plants alter their chemistry to defend against insect attacks.

Insect communication: Many insects rely on pheromones and chemical signals. Metabolomic profiling identifies these compounds, aiding in the development of eco-friendly pest management strategies like pheromone traps.

Disease vectors: In mosquitoes, metabolomics has shown how malaria parasites alter host metabolism, offering new intervention points.

Through metabolomics, entomologists gain insights into the "chemical language" of insects.

Epigenomics: Beyond the Genetic Code

Epigenomics examines how environmental factors modify gene expression without changing the DNA sequence itself. In insects, epigenetic modifications like DNA methylation or histone modification influence behavior, caste differentiation, and adaptation.

Social insects: In honeybees, epigenomic changes decide whether a larva develops into a worker or a queen, despite having the same genetic code.

Insecticide resistance: Epigenetic regulation can turn on detoxification genes, enabling pests to adapt quickly to new chemicals.

Transgenerational effects: Epigenomic studies show how parental exposure to stress or toxins can influence offspring traits, relevant for predicting pest resilience.

Epigenomics adds another layer of complexity, showing that genes are not destiny but are regulated by flexible molecular switches.

Microbiomics: The Hidden Allies and Enemies

Insects harbor diverse microbial communities bacteria, fungi, and viruses that influence their health, development, and ecological roles.

Symbionts in pests: Endosymbiotic bacteria like Wolbachia manipulate insect reproduction and reduce vector competence in mosquitoes, offering a biological control strategy.

Gut microbiota: In termites, gut microbes digest cellulose, while in mosquitoes they influence pathogen transmission. Manipulating gut microbiota is an emerging area in pest and vector management.

Pollinator health: Microbiome studies in bees have identified beneficial bacteria that enhance immunity and digestion, highlighting the role of microbial balance in pollinator decline.

Microbiomics reminds us that insect biology is not just about the insect itself but also its invisible microbial partners.

Applications of Omics in Entomology

Pest Management: Omics tools provide insights into resistance mechanisms, pest population genetics, and novel control targets. For example, transcriptomic markers can detect early signs of insecticide resistance, while metabolomic studies aid in pheromone-based integrated pest management (IPM).

Vector Biology and Disease Control: Genomic and transcriptomic data are being used to design genetically modified mosquitoes that are resistant to malaria parasites. Microbiome manipulation through Wolbachia is already being field-tested in dengue control programs.

Pollinator Conservation: Honeybee genomics and proteomics have revealed stress responses to pesticides, pathogens, and nutrition deficits. These findings inform sustainable agricultural practices that protect pollinators.

Biodiversity and Evolution: Comparative genomics across insect species sheds light on evolutionary adaptation, speciation, and biodiversity conservation. DNA barcoding, based on genomics, allows rapid insect identification for ecological studies.

Climate Change Studies: Transcriptomic and metabolomic analyses reveal how insects cope with heat stress, drought, or changing host plants, helping predict shifts in pest ranges under global warming.

Future Prospects

The integration of multiple omics so-called systems biology is the future of entomology. By combining genomics, proteomics, metabolomics, and epigenomics, researchers can build holistic models of insect biology. Artificial intelligence and machine learning will further accelerate data analysis, turning omics into predictive tools. However, challenges remain, including high costs, complex data interpretation, and ethical considerations in releasing genetically modified insects.

Conclusion

Omics has opened a new era in entomology, enabling scientists to move from descriptive studies to predictive and applied sciences. From decoding insect genomes to profiling their microbiomes, these approaches provide unprecedented insights into insect biology. The applications in pest management, pollinator protection, and vector control demonstrate how omics is not only advancing fundamental knowledge but also addressing global challenges in agriculture, health, and the environment.

As omics technologies continue to evolve, the tiny world of insects will no longer remain hidden. Instead, it will be illuminated at molecular detail, offering innovative solutions for a sustainable future.

Smart Fertigation: Boosting Chilli Productivity with Science-Driven Nutrient Management

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Abstract

Fertigation is the combined application of fertilizers with irrigation water, is an efficient and precise method of supplying nutrients to crops. In chilli (*Capsicum annuum* L.), fertigation enhances nutrient uptake, improves fertilizer use efficiency, reduces nutrient losses, and ensures uniform growth and higher yields. Efficient fertigation scheduling depends on soil characteristics, irrigation water quality, and crop growth stages. This article summarizes scientific principles, recommended practices, and monitoring strategies for successful fertigation management in chilli cultivation under Indian conditions. Emphasis is placed on nutrient scheduling, fertilizer compatibility, monitoring of pH and electrical conductivity (EC), and integration of micro- and secondary nutrients to optimize productivity and sustainability.

Introduction

Chilli (*Capsicum annuum* L.) is one of the most important commercial spice and vegetable crops in India, valued for its pungency, colour, and medicinal properties. India ranks among the largest producers and exporters of chilli globally. The crop is highly responsive to efficient nutrient management due to its shallow root system and high nutrient uptake rate (Singh *et al.*, 2020). Traditional fertilizer broadcasting methods often result in poor nutrient use efficiency, nutrient leaching, and inconsistent yields. Fertigation is the application of soluble fertilizers through drip irrigation to ensures precise timing, uniform distribution, and better nutrient availability to the root zone (Reddy *et al.*, 2017). Hence, fertigation is a promising technology for sustainable chilli production, especially under intensive cultivation and water-limited conditions.

Principles of Fertigation

Fertigation combines irrigation and fertilization into one operation, reducing labour and increasing nutrient use efficiency (FAO, 2016). The following principles are essential:

Split nutrient application: Nutrients should be supplied in multiple small doses matching crop uptake pattern.

Balanced nutrient ratios: Maintain appropriate N:K ratio (1:1.2 to 1:1.5) for optimum fruiting.

Water quality consideration: Fertilizer choice depends on water pH, bicarbonate levels, and EC.

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Compatibility: Incompatible fertilizers (e.g., Ca with sulphate or phosphate) should not be mixed in the same stock solution (TNAU, 2022).

Monitoring: Regularly monitor fertigation solution EC and pH to maintain root zone balance.

Nutrient Requirement and Scheduling

Nutrient requirement varies with soil type, hybrid, and yield target. A generalized recommendation for open-field chilli is 150-200 kg N, 75-100 kg P_2O_5, and 150-200 kg K_2O ha^{-1}, to be adjusted based on soil test results (ICAR-NRCSS, 2021).

Growth Stage	Weeks After Transplanting	N (%)	P_2O_5 (%)	K_2O (%)
Establishment	0-4	10-15	15	10
Vegetative	5-8	25	25	30
Flowering	9-12	30	30	30
Fruiting & Harvest	13-20	35	30	30

Micronutrients: Fe, Zn, Mn, B, and Cu can be supplied via chelated fertigation or foliar sprays (e.g., Fe-EDDHA, Zn-EDTA at 0.2%). Calcium nitrate ($Ca(NO_3)_2$) and magnesium sulphate ($MgSO_4$) are commonly used for secondary nutrients.

Fig. 1: General field view of chilli crop under fertigation schedule

Fertigation Management Practices

Use water-soluble fertilizers such as urea, calcium nitrate, potassium nitrate, monoammonium phosphate (MAP), and sulphate of potash (SOP). Avoid mixing calcium nitrate with sulphate or phosphate fertilizers in the same tank (FAO, 2016). Apply fertigation 2-3 times per week in open fields or daily in protected cultivation. Maintain solution pH 5.5-6.5 and EC 1.2-2.0 dS m^{-1} depending on water quality (Reddy *et al.*, 2017).

Monitoring and Troubleshooting

Common issues and corrective actions during fertigation are listed below:

Problem	Likely Cause	Corrective Action
High EC (>2.5 dS m^{-1})	Excess fertilizer or saline water	Dilute solution; leach salts
Clogging of emitters	Precipitation of salts	Use acid flushing and filtration
Blossom end rot	Calcium deficiency	Supply $Ca(NO_3)_2$ via fertigation
Leaf chlorosis	Fe or Zn deficiency	Apply chelated micronutrients
Excess vegetative growth	High N:K ratio	Increase K relative to N

Environmental and Economic Benefits

Fertigation increases nutrient-use efficiency by 25-40% and can save 30-40% fertilizer compared to conventional application (Singh *et al.*, 2020). Water saving up to 40-50% has been reported under drip fertigation in chilli. Environmentally, it minimizes nutrient leaching and nitrate contamination in groundwater (Patel *et al.*, 2021).

Conclusion

Efficient fertigation management in chilli ensures balanced nutrition, enhances yield and quality, and contributes to sustainable resource use. Adoption of water-soluble fertilizers, regular monitoring of EC and pH, and stage-wise nutrient scheduling are key success factors. Integration of fertigation with soil and foliar nutrition strategies ensures optimum productivity and profitability for chilli growers.

References

FAO. (2016). Fertigation: A tool for efficient fertilizer and water management. Food and Agriculture Organization of the United Nations, Rome.

ICAR-NRCSS. (2021). Package of Practices for Chilli and Other Spices. ICAR-National Research Centre on Seed Spices, Ajmer, India.

Patel, M. K., Singh, S. K. and Meena, R. S. (2021). Drip fertigation for efficient nutrient and water use in vegetable crops: A review. *Journal of Plant Nutrition*, 44(12): 1791-1806.

Reddy, K. M., Rao, K. P. and Reddy, D. S. (2017). Effect of drip fertigation on growth and yield of chilli (*Capsicum annuum* L.). *International Journal of Current Microbiology and Applied Sciences*, 6(7): 1967-1975.

Singh, R., Kumar, A. and Sharma, P. (2020). Integrated nutrient management in chilli for enhanced productivity. *Scientia Horticulturae*, 262: 109046.

TNAU (2022). Crop Production Guide: Chilli. Tamil Nadu Agricultural University, Coimbatore, India.

Vermicomposting: Nature's Way to Healthy Soil and Healthy Crops

S. Nisha, R. Vedhanayagi and T. Ilakiya

Introduction

In recent years, people have shown increasing interest in natural methods such as composting and vermicomposting, which convert organic materials into nutrient-rich products. Composting involves the continuous decomposition of organic waste under open environmental conditions, while vermicomposting is a similar biological process that takes place with the active participation of earthworms. In vermicomposting, a symbiotic interaction between earthworms and microorganisms transforms organic matter into a stable product known as vermicompost. Compared to traditional compost, vermicompost is physically and nutritionally superior because it enhances the mineralization rate of organic matter, making nutrients more readily available. The products of these processes include both earthworm biomass and vermicompost itself, which are beneficial for soil health. An integrated system of composting and vermicomposting can effectively control pathogens while producing high-quality organic fertilizers. During vermicomposting, earthworms reduce particle size, mix the organic matter, and accelerate nutrient release. Their feeding activity on decayed manure results in excretion of digested material, known as worm cast, which is often referred to as "Black Gold" due to its richness in essential nutrients that promote plant growth.

Thus, vermicomposting can be described as the process of using earthworms to recycle agricultural waste into valuable organic compost. Earthworms act as activators, crushers, and mixers of the soil, making decomposition easier and faster. The resulting vermicompost improves soil quality through its physical, chemical, and biological properties.

Production process of Vermicomposting

Material required for vermicomposting

- ✓ Raw materials
- ✓ Selection of earthworm
- ✓ Site selection
- ✓ Containers used for vermicompost production

Raw materials: The raw materials used for the composting process include vegetable waste, kitchen waste, industrial waste, hotel waste, and other biodegradable materials. Both urban and rural wastes can serve as inputs for compost production. In addition, leguminous and non-leguminous crop residues are also commonly utilized as raw materials.

Site selection: Site selection for composting should preferably be in abandoned cattle sheds, poultry sheds, or other unused constructed buildings. When composting is carried out in an open area, it is advisable to provide artificial shading to protect the process from direct sun and rain.

Containers used for vermicompost production: For vermicompost production, different types of

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containers can be used, such as cement pits, plastic buckets, or wooden boxes. Cement pits are usually constructed with bricks, having a width of about 3 feet and a length adjusted as per convenience. When using wooden boxes or plastic buckets, it is important to ensure the provision of proper drainage holes to allow excess water to escape and maintain suitable conditions for earthworms.

Selection of earthworm

Surface dwelling earthworms are suitable for Vermicompost. They are

- ✓ *Eisenia fetida* (Exotic worms)
- ✓ *Eudrilus eugeniae* (Exotic worms)
- ✓ *Perionyx excavatus* (Native to India)

Important characteristics of red earthworm

- ✓ Body length: 3-10 cm
- ✓ Body weight: 0.4-0.6
- ✓ Maturity: 50-55 days
- ✓ Conversion rate: 2.0 q/1500 Worm/2 month
- ✓ Cocoon production: 1 in every 3 days
- ✓ Incubation of cocoon: 20-23 days

Favourable condition for earthworm

- ✓ pH-neutral (6.5 to 7.5)
- ✓ Moisture content-60 to 70%
- ✓ Aeration -50 %
- ✓ Temperature -180°C-350°C

Five phases of vermicomposting

- ✓ Phase-Collection of waste material
- ✓ Phase-Pre -digestion of vermicompost
- ✓ Phase-Earthworm bed preparation and composting
- ✓ Phase-Harvesting of vermicompost and earthworm
- ✓ Phase-Packaging and storage of vermicompost

Collection of waste material: The waste materials should first be collected and separated using mechanical methods, after which they are stored properly for further processing.

Pre -digestion of Vermicompost: The collected raw materials are heaped and mixed with cow dung slurry to initiate decomposition. Care must be taken to avoid using dry cattle manure, as it generates excessive heat that may harm the process. The composting process generally requires 20 to 25 days for completion.

Earthworm bed preparation and composting: In preparing the bed for vermicompost production, five important factors must be ensured: bedding material, adequate food source, proper moisture, aeration, and protection from extreme temperatures. The bedding is usually prepared using organic residues such as sawdust, coir waste, leaf litter, sugarcane residues, and other biodegradable wastes. These materials are placed as the bottom layer of the bed, with light watering to allow proper settling. This layer should be about 3 cm thick. Over this, a layer of fine sand (3 cm thickness) is spread to facilitate drainage and movement of earthworms. Finally, earthworms are introduced at an appropriate ratio on the top layer to begin the vermicomposting process.

Harvesting of Vermicompost: The first harvest of vermicompost can be done after about two months. By this time, the top layer of worm castings will have formed and can be collected using gentle scooping.

The harvested compost should be collected regularly and stored in a shady, well-ventilated area to maintain its quality. During the harvesting stage, care must be taken to ensure a free flow of air within the compost. Overwatering should be avoided, as it can cause compaction and reduce the quality of the vermicompost.

Packaging and storage of Vermicompost: The harvested vermicompost should be stored in dark, cool places, protected from direct sunlight. Ideally, storage should be in a compact and well-shaded condition to preserve quality. The moisture content should be maintained around 40%. After proper storage, the vermicompost can be packed in plastic bags or gunny sacks for use or sale.

Method of vermicomposting

Vermi composting has two methods they are bed method and pit method:

Bed method Pit method

Fig 1: Methods of vermicomposting

Nutrient Content

Nutrient	Content
Total nitrogen	1.5 to 2.10 %
Total phosphorus	1.0 to 1.50 %
Total potassium	0.60%
Organic carbon	9.15 to 17.98 %
Ca and Mg	22.00 to 70.00 meq /100 g
Zinc	50 ppm
Iron	1800 ppm
Copper	100 ppm
Available S	128 to 548 ppm

Conclusion

Vermicompost is a valuable, eco-friendly organic fertilizer and soil conditioner suitable for use in home gardens as well as large-scale farming. It helps prevent nutrient losses and improves the efficiency of chemical fertilizers. Additionally, vermicompost is rich in essential nutrients, vitamins, enzymes, and plant growth-promoting hormones such as auxins and gibberellins, which enhance overall plant growth and productivity.

References

Lim, S. L., Wu, T. Y., Lim, P. N. and Shak, K. P. Y. (2015). The use of vermicompost in organic farming: overview, effects on soil and economics. *Journal of the Science of Food and Agriculture*, 95(6): 1143-1156.

Yatoo, A. M., Ali, M. N., Baba, Z. A. and Hassan, B. (2021). Sustainable management of diseases and pests in crops by vermicompost and vermicompost tea. A review. *Agronomy for Sustainable Development*, 41(1): 7.

Edwards, C. A., Arancon, N. Q. and Greytak, S. (2006). Effects of vermicompost teas on plant growth and disease. *Biocycle*, 47(5): 28.

Growth of Dairy Cooperative in Haryana

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Abstract

Dairy cooperatives in Haryana have played a vital role in transforming the state's rural economy and dairy sector. Originating during India's White Revolution, these cooperatives, led by the Haryana Dairy Development Cooperative Federation (HDDCF), have helped farmers achieve fair prices and steady incomes by eliminating middlemen and improving market access. With significant investments in modern infrastructure, such as the Sabar Dairy plant in Rohtak, Haryana has boosted production and quality of milk and dairy products. Beyond economic growth, cooperatives have empowered rural communities, especially women, promoting social inclusion and livelihood security. Despite challenges like price fluctuations and competition, ongoing efforts in training, technology, and policy support continue to strengthen Haryana's dairy cooperatives, making them a model for rural development and sustainable dairy farming in India.

The Rise of Dairy Cooperatives in Haryana: A Model of Rural Transformation

Haryana, a state in northern India known for its fertile fields and vibrant agricultural heritage, has quietly become a powerhouse in the dairy industry. Behind this success is the steady rise of dairy cooperatives that have transformed the lives of thousands of rural farmers. These cooperatives not only ensure fair prices and steady incomes for milk producers but also contribute significantly to the state's economy and social fabric. This article explores the journey, growth, and future prospects of dairy cooperatives in Haryana, highlighting how collective effort and modern innovation have created a thriving dairy sector.

The Genesis of Dairy Cooperatives in Haryana

The story of Haryana's dairy cooperatives begins during India's White Revolution in the 1970s. The government, aiming to boost milk production nationwide, supported the formation of cooperative societies where farmers could collectively manage production and marketing. Haryana Dairy Development Cooperative Federation Ltd (HDDCF) emerged as a key player in this movement. By organizing farmers and eliminating middlemen, the federation guaranteed fair prices and timely payments to producers, helping build trust in the cooperative

Fig. 1: Milk collection centers in villages

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Economic Impact and Growth Metrics

The growth of Haryana's dairy cooperatives has been impressive. Between 2019 and 2022, the HDDCF's turnover increased from ₹1,159 crore to an estimated ₹1,505 crore, while profits rose from ₹11.50 crore to ₹49.57 crorean all-time high. This surge is fueled by rising demand for dairy products such as milk, ghee, curd, and lassi, with sales increasing significantly in the April-June 2022 quarter compared to the previous year. This financial success reflects the cooperatives' role in providing quality products and steady incomes to farmers.

Infrastructure Development and Technological Advancements

Key to Haryana's dairy success has been investment in infrastructure. The state boasts modern dairy processing plants like the Sabar Dairy plant in Rohtak, the largest cooperative curd plant in India. With an investment of ₹350 crore, this plant processes 150 metric tonnes of curd, 3 lakh litres of buttermilk, and 10,000 kilograms of sweets daily, catering to Haryana and the Delhi-NCR region. Such facilities ensure high-quality production to meet growing demand.

Empowerment of Farmers and Rural Development

Beyond economics, dairy cooperatives have transformed rural society in Haryana. They provide women and marginalized farmers with steady incomes, reducing dependence on traditional farming and improving livelihoods. Cooperative membership brings social empowerment, offering training and community engagement. Direct procurement ensures farmers get fair prices and timely payments, encouraging more to join.

Fig. 2: Women engaged in dairy farming

Challenges and the Path Forward

While progress is remarkable, challenges remain. Fluctuating milk prices, competition from private dairies and the need for continuous technological upgrades require attention. The way forward includes capacity building through farmer training, infrastructure upgrades, supportive government policies, and investment in research to improve breeds and feed efficiency.

Fig. 3: Automated milking machines

Conclusion

The growth of dairy cooperatives in Haryana is a powerful example of how cooperative principles and modern innovation can uplift rural economies. With a focus on quality, infrastructure, and farmer empowerment, Haryana is setting standards for India's dairy industry. As the sector continues to evolve, it promises even greater contributions to the state and national economy.

Transforming Agriculture in a Changing Climate: The Role of Climate Smart Practices

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Introduction

Agriculture remains the backbone of many economies, especially in developing nations, where it supports livelihoods, ensures food security, and contributes significantly to GDP. However, the sector is increasingly threatened by the impacts of climate change, which include rising temperatures, erratic rainfall patterns, prolonged droughts, and frequent extreme weather events. These climatic stresses have severely affected crop productivity, soil fertility, and water availability, making traditional farming systems less reliable (IPCC, 2023). The growing pressure on natural resources has intensified the need for sustainable and adaptive agricultural practices. In this context, Climate Smart Agriculture (CSA) has emerged as a holistic and innovative approach designed to transform and reorient agricultural systems to effectively respond to climate challenges. CSA aims to simultaneously achieve three key objectives: increasing agricultural productivity and incomes, enhancing resilience and adaptation to climate variability, and reducing or removing greenhouse gas emissions (FAO, 2013). By integrating technological innovation, resource efficiency, and ecological balance, CSA provides a pathway toward sustainable food systems and climate-resilient rural livelihoods.

What is Climate Smart Agriculture?

The Food and Agriculture Organization (FAO) defines Climate Smart Agriculture (CSA) as an integrated approach that aims to sustainably increase productivity, enhance resilience (adaptation), reduce or remove greenhouse gas emissions (mitigation), and strengthen national food security and development goals (FAO, 2010). Unlike conventional agricultural systems that primarily focus on maximizing yields, CSA emphasizes long-term sustainability by promoting ecosystem balance, resource efficiency, and climate adaptability. It incorporates innovative farming techniques, efficient input use, and ecosystem-based management to ensure both environmental and economic stability. By addressing productivity, adaptation, and mitigation together, CSA represents a forward-looking model that aligns agricultural growth with climate resilience and sustainable development (Lipper *et al.*, 2014).

Why Climate Smart Agriculture is the Best option

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CSA offers multiple benefits across productivity, resilience and environmental sustain-ability. It is the best pathway to transform agriculture under climate uncertainty.

Enhancing Productivity and Food Security: CSA technologies such as drought-tolerant crop varieties, integrated nutrient management, and precision farming help maintain or improve productivity even under climate stress (World Bank, 2022). Efficient irrigation methods like drip and sprinkler systems minimize water losses while improving crop yields. These interventions are vital for ensuring food security in regions like South Asia and Sub-Saharan Africa, where smallholder farmers dominate (Aggarwal *et al*., 2018).

Building Climate Resilience: Climate resilience is central to Climate Smart Agriculture (CSA), enabling farmers to withstand and recover from climatic shocks. Practices such as crop diversification, agroforestry, and conservation agriculture enhance adaptive capacity and reduce vulnerability (Thorpe *et al.*, 2021). Agroforestry improves soil fertility, boosts water retention, and provides shade, protecting crops from heat and drought stress. These adaptive strategies help stabilize yields, secure farmers' incomes and ensure agricultural sustainability in the face of increasing climate variability and extreme weather events.

Reducing Greenhouse Gas Emissions: Agriculture contributes about 25% of global greenhouse gas emissions (IPCC, 2023). Climate Smart Agriculture (CSA) provides effective mitigation strategies through improved fertilizer efficiency, methane reduction in rice fields, and sustainable manure management in livestock systems (Smith *et al.*, 2019). Additionally, practices like conservation tillage and organic soil management enhance carbon sequestration, transforming agricultural lands into vital carbon sinks while promoting environmental sustainability.

Promoting Sustainable Resource Use: Efficient resource utilization is a fundamental aspect of Climate Smart Agriculture (CSA). Techniques such as laser land leveling, mulching, precision irrigation, and integrated pest management (IPM) help minimize water wastage, reduce energy consumption, and lower chemical dependency (Pretty *et al.*, 2018). These practices improve soil health, optimize input use, and conserve natural resources, thereby maintaining ecological balance. By promoting efficient and sustainable resource management, CSA ensures that agricultural productivity increases without degrading the environment, supporting both long-term environmental sustainability and economic viability for farming communities.

Empowering Farmers and Rural Communities: Climate Smart Agriculture (CSA) is a participatory and knowledge-driven approach that bridges traditional wisdom with modern scientific innovation. It empowers farmers to make informed, climate-resilient decisions through access to real-time information and adaptive technologies. Tools such as climate information services, ICT-based advisory platforms, and early warning systems help farmers anticipate weather risks, manage resources efficiently, and plan cropping patterns strategically. By enhancing knowledge, participation, and technological access, CSA strengthens community resilience, supports sustainable livelihoods, and promotes inclusive agricultural development in the face of climate uncertainty (Rasul and Sharma, 2016).

Examples of Climate Smart Practices

Conservation Agriculture (CA): Minimal soil disturbance, permanent soil cover, and crop rotation.

Agroforestry: Integration of trees with crops and livestock.

Integrated Crop-Livestock Systems: Recycling nutrients through manure use.

Digital Agriculture: Satellite imagery and mobile apps providing weather and soil data.

Water Harvesting and Efficient Irrigation: Farm ponds, drip systems, and rainwater storage.

Challenges in Adopting CSA

Adopting Climate Smart Agriculture (CSA) presents multiple challenges, particularly in developing regions where farmers often face limited awareness, financial constraints, and inadequate technical knowledge. Weak institutional frame-works, poor infrastructure, and insufficient access to markets and climate information further restrict the implementation of CSA practices. Additionally, the absence of supportive policies and extension services hinders widespread adoption. Overcoming these barriers requires strong policy reforms, targeted financial support and investment in capacity building and rural innovation. Collaborative efforts among governments, research institutions, and communities are essential to scale up CSA and ensure climate-resilient, sustainable agricultural development (World Bank, 2022).

Policy and Institutional Support

Effective policy and institutional support are essential for mainstreaming Climate Smart Agriculture (CSA). Governments should integrate CSA into national agricultural and climate policies, such as National Adaptation Plans (NAPs) and Nationally Determined Contributions (NDCs). Financial incentives, credit access, and crop insurance schemes can encourage farmers to adopt sustainable practices. Strengthening agricultural extension services and research institutions is vital to promote CSA technologies at the grassroots level. Collaboration between government agencies, NGOs, and private sectors can enhance capacity building and technology transfer. A supportive policy framework ensures that CSA becomes a long-term strategy for climate-resilient and sustainable agriculture. Governments play a crucial role in mainstreaming CSA through integration into National Adaptation Plans, Nationally Determined Contributions, and agricultural development strategies (FAO, 2021).

Conclusions

Climate Smart Agriculture (CSA) represents the most viable pathway for achieving sustainable agricultural growth in the face of climate change. By integrating productivity, resilience and environmental sustainability, CSA enhances food security while reducing vulnerability to climate shocks. Its adaptive techniques ranging from conservation farming to efficient water management enable farmers to maintain yields and incomes sustainably. Moreover, CSA contributes to climate change mitigation by lowering greenhouse gas emissions and improving soil carbon sequestration. To ensure its large-scale adoption, strong institutional support, research innovation, and farmer participation are essential. Ultimately, CSA secures both agricultural sustainability and ecological balance for future generations.

References

Aggarwal, P. K., Jarvis, A., Campbell, B. M., Zougmoré, R. B., Khatri-Chhetri, A., Vermeulen, S. J. and & Wollenberg, E. (2018). The climate-smart village approach: Framework of an integrative strategy for scaling up adaptation options in agriculture. *Ecology and Society*, 23(1): 14.

FAO. (2010). Climate-Smart Agriculture: Policies, Practices and Financing for Food Security, Adaptation and Mitigation. FAO.

FAO. (2013). Climate-Smart Agriculture Source-book. FAO.

FAO. (2021). The State of Food and Agriculture 2021: Making agrifood systems more resilient to shocks and stresses. FAO.

IPCC. (2023). Climate Change 2023: Synthesis Report. Geneva: IPCC.

Lipper, L., Thornton, P., Campbell, B. M., Baedeker, T., Braimoh, A., Bwalya, M., ... and Torquebiau, E. F. (2014). Climate-smart agriculture for food security. *Nature Climate Change*, 4(12): 1068-1072.

Pretty, J., Benton, T. G., Bharucha, Z. P., Dicks, L. V., Flora, C. B., Godfray, H. C. J., ... and Wratten, S. (2018). Global assessment of agricultural system redesign for sustainable intensification. *Nature Sustainability*, 1(8): 441-446.

Rasul, G. and Sharma, B. (2016). The nexus approach to water-energy-food security: An option for adaptation to climate change. *Climate Policy*, 16(6): 682-702.

Smith, P., Soussana, J. F., Angers, D., Schipper, L., Chenu, C., Rasse, D. P., ... and Lal, R. (2019). How to measure, report and verify soil carbon change to realize the potential of soil carbon sequestration for atmospheric greenhouse gas removal. *Global Change Biology*, 26(1): 219-241.

Thorpe, A., Nkiaka, E. and Conway, D. (2021). Adaptation to climate change through water-smart agriculture in sub-Saharan Africa. *Climate and Development*, 13(6): 495-507.

World Bank. (2022). Climate Smart Agriculture Investment Plan: Building Resilience in Agricultural Systems. Washington, DC: World Bank Group.

Improving Productivity in Banana Cultivation: A Kerala Perspective

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Abstract

Banana cultivation is a crucial agricultural activity deeply embedded in the cultural and economic fabric of Kerala. The state's tropical climate, abundant annual rainfall (over 3000 mm), and rich soil including lateritic and alluvial types create an ideal environment for the crop. Bananas are a staple food, a source of livelihood, and hold significant cultural value in festivals and ceremonies. Popular varieties include Nendran (the “king of bananas”), Red Banana (Chenkadali), and Poovan. Farmers employ techniques like using tissue culture plantlets, drip irrigation, and integrated pest management. However, challenges persist, such as severe threats from Panama wilt and bacterial wilt, pest damage, and market volatility. Government support and the adoption of modern, sustainable techniques are key to maximizing yields and ensuring the continued economic and social importance of banana cultivation in Kerala.

Introduction

Bananas hold a special place in Kerala’s agricultural landscape. Known as one of the most important fruit crops in the state, banana cultivation has been deeply woven into the cultural and economic fabric of Kerala. With its favorable climate, rich soil, and ample rainfall, Kerala provides an ideal environment for growing bananas. This article explores the significance, methods, challenges and prospects of banana cultivation in Kerala.

Fig. 1: Banana plants with developing bunches in a Kerala plantation

Importance of Banana Cultivation in Kerala

Banana is a staple fruit consumed widely across Kerala. Apart from being a source of nutrition and livelihood for many farmers, it also has cultural significance, especially in festivals and religious ceremonies. The versatility of bananas from raw to ripe consumption and usage in various dishes makes it an indispensable crop. Kerala ranks among the top banana-producing states in India. The crop is cultivated on both small and large scales, contributing substantially to the state’s horticulture economy. The demand for bananas locally and in nearby states ensures good market prospects for growers.

Climatic and Soil Conditions

Kerala’s tropical climate is perfect for banana cultivation. Bananas require warm temperatures ranging between 26°C and 30°C, and Kerala’s consistent rainfall supports this need.

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The state receives abundant rainfall, usually more than 3000 mm annually, which keeps the soil moist and fertile. The soil type preferred for banana cultivation is well-drained, deep loamy soil rich in organic matter. Kerala's lateritic and alluvial soils provide the necessary nutrients and drainage for healthy growth. Proper soil preparation and management are crucial for high yields.

Popular Banana Varieties in Kerala

Several banana varieties are grown in Kerala, each with unique characteristics. Some of the most popular include:

Nendran: Known as the king of bananas in Kerala, Nendran bananas are large, robust, and used extensively for cooking (especially for making chips) and consumption.

Red Banana (Chenkadali): This variety is smaller, with a reddish peel and a sweet taste.

Pacha Nendran: Similar to Nendran but harvested earlier, used mostly for cooking.

Poovan: A sweet banana variety favored for dessert purposes.

Monthan: Used for making banana chips and also consumed as ripe fruit.

Fig. 2: Harvested ripe yellow bananas

These varieties are adapted to different growing conditions, and farmers choose them based on market demand and climatic suitability.

Steps in Banana Cultivation

Selection of Land: Farmers select land with good sunlight exposure, proper drainage, and access to irrigation.

Soil Preparation: The soil is plowed and mixed with organic manure like cow dung or compost to enrich it.

Planting: Banana plants are usually propagated through suckers or tissue culture plantlets. Suckers are young shoots that grow from the base of the banana plant. Planting is done in pits filled with organic matter to support root growth.

Spacing: Proper spacing (around 2.5 to 3 meters apart) is maintained to avoid competition for nutrients and sunlight.

Irrigation: Though bananas require lots of water, overwatering can cause root diseases. Drip irrigation is becoming popular to provide adequate water while conserving resources.

Fertilization: Regular application of nitrogen, phosphorus, potassium and micronutrients is essential. Organic fertilizers are also widely used.

Weeding and Mulching: Keeping the banana field free from weeds helps reduce competition. Mulching with dried leaves or plastic sheets conserves soil moisture and suppresses weeds.

Pest and Disease Management: Bananas are susceptible to pests like banana weevil and diseases like Panama wilt and bunchy top virus. Integrated pest management, including biological controls and resistant varieties, helps reduce losses.

Harvesting: Bananas are harvested when the fruit reaches maturity but is still green. The timing varies depending on the variety and use (raw or ripe consumption).

Challenges in Banana Cultivation

Fig. 3: Banana plants damaged by heavy rain or a storm

Despite favorable conditions, banana farming in Kerala faces several challenges:

Diseases: Panama wilt and bacterial wilt are serious threats. These soil-borne diseases reduce yield and may destroy entire plantations if not managed properly.

Pests: The banana stem borer and aphids cause significant damage.

Weather Extremes: Heavy rains and floods can cause waterlogging, while drought affects growth.

Market Fluctuations: Prices can be volatile, affecting farmers' income.

Labour Intensive: Banana cultivation requires considerable manual labor, which can be a constraint.

Government Support and Modern Techniques

The Kerala government promotes banana cultivation through subsidies, training programs, and support for tissue culture technology. Tissue culture plants ensure disease-free and uniform planting material, improving yields and quality. Modern techniques like drip irrigation, integrated pest management, and organic farming are gaining popularity. These methods reduce environmental impact and enhance productivity.

Economic and Social Impact

Banana cultivation provides employment opportunities to many rural families in Kerala. It supports not only farmers but also laborers involved in planting, harvesting, and processing. Banana-based products such as chips, desserts, and fiber crafts contribute to local economies. The crop's importance in Kerala's cuisine, festivals, and traditions also highlights its cultural value.

Conclusion

Banana cultivation in Kerala is a thriving agricultural activity with significant economic, nutritional, and cultural importance. While the state's favorable climate and soil conditions provide a perfect environment for growth, challenges like diseases and market uncertainties need continuous attention. Adoption of modern farming techniques and government support can help banana farmers maximize yields and profits. As Kerala continues to embrace sustainable agriculture, banana cultivation stands as a symbol of fruitful harmony between tradition and innovation.

Biofortification in Vegetables: A Sustainable Approach to Nutritional Security

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Abstract

Malnutrition and micronutrient deficiencies, commonly known as "hidden hunger," affect a large proportion of the global population. Vegetables, being nutrient-dense crops, play a vital role in human nutrition. Biofortification enhancing the nutritional quality of crops through agronomic, conventional breeding, or biotechnological approaches offers a promising and sustainable solution to combat micronutrient malnutrition. This article discusses the concept, methods, importance, and prospects of biofortification in vegetable crops.

Introduction

Nutrition security is emerging as a critical global challenge. While food availability has improved, the nutritional quality of food remains a concern, particularly in developing countries. Micronutrient malnutrition, primarily caused by deficiencies of iron (Fe), zinc (Zn), vitamin A and iodine, affects billions of people worldwide. Vegetables are an excellent source of vitamins, minerals, antioxidants, and phytonutrients, making them suitable targets for biofortification programs. Biofortification is defined as the process of increasing the density of vitamins and minerals in a crop through plant breeding, genetic engineering, or agronomic practices. Unlike food fortification, which adds nutrients during food processing, biofortification enhances nutrient content naturally during crop growth and ensuring long-term sustainability.

Methods of Biofortification in Vegetables

Conventional Breeding: Traditional breeding involves crossing high-yielding varieties with nutrient-rich parental lines to produce biofortified cultivars. For example, high β-carotene content has been successfully introduced into carrot, pumpkin, and sweet potato through selective breeding.

Agronomic Biofortification: This method involves the application of mineral fertilizers or foliar sprays to enhance the nutrient content of vegetables. For instance, applying zinc sulfate or iron chelates to soils or leaves can increase Zn and Fe concentration in spinach, tomato, and cabbage.

Genetic Engineering: Modern biotechnology enables the direct modification of genes responsible for nutrient synthesis or uptake. Genetic engineering has been used to develop iron-rich tomato, β-carote-

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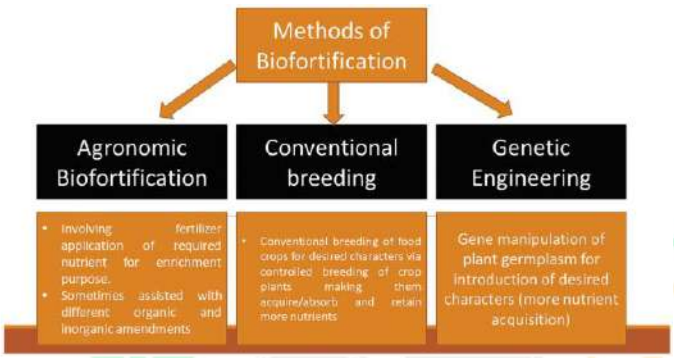
ne-enriched lettuce, and folate-enhanced potato. This approach provides faster and more precise results compared to conventional breeding.

Microbial Biofortification: Utilization of beneficial soil microbes such as mycorrhizal fungi and plant growth-promoting rhizobacteria (PGPR) can improve nutrient uptake efficiency. This eco-friendly approach enhances micronutrient accumulation in crops without harming soil health.



Important Biofortified Vegetable Examples

Crop	Nutrient Enhanced	Approach Used	Remarks
Carrot	β-carotene (Vitamin A)	Conventional breeding	Improves vision and immune health
Spinach	Iron, Zinc	Agronomic fortification	Reduces anemia
Tomato	Lycopene, Iron	Genetic modification	Enhances anti-oxidant activity
Sweet Potato	β-carotene	Breeding and transgenic	Excellent source of Vitamin A
Onion & Garlic	Selenium	Agronomic fortification	Antioxidant and anticancer properties

Importance and Benefits

Addresses Hidden Hunger: Helps combat micro-nutrient deficiencies sustainably.

Cost-Effective: Once developed, biofortified varieties require no recurring cost for nutrient addition.

Environmentally Friendly: Reduces dependence on chemical supplements.

Enhances Human Health: Improves immunity, cognitive development, and productivity.

Supports SDG Goals: Contributes directly to Sustainable Development Goal 2 - Zero Hunger.

Challenges in Biofortification

- ✓ Limited genetic variability in some vegetable species.
- ✓ Consumer acceptance of biofortified produce (especially transgenic types).
- ✓ Lack of awareness among farmers and policymakers.
- ✓ Nutrient stability during post-harvest storage and cooking.

Overcoming these challenges requires integrated efforts involving plant breeders, nutritionists, policymakers, and extension workers.

Future Prospects

With advancements in genomics, molecular breeding, and nanotechnology, biofortification has immense potential. Integrating biofortification programs into national nutrition policies and promoting consumer awareness can accelerate adoption. Collaborative initiatives like HarvestPlus and ICAR's biofortification programs in India are already showing promising results in cereals and can be extended to vegetables on a larger scale.

Conclusion

Biofortification in vegetables represents a sustainable, cost-effective, and farmer-friendly approach to enhance the nutritional quality of diets. By incorporating nutrient-enriched vegetable varieties into mainstream agriculture, countries can significantly reduce the prevalence of hidden hunger and improve public health outcomes. Thus, biofortification stands as a vital tool for achieving global nutritional security.

Automation in Seed Processing and Packaging

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Abstract

Automation in seed processing and packaging has revolutionized modern seed industries by improving efficiency, precision, and quality assurance. Through the use of advanced technologies like robotics, artificial intelligence (AI), sensors, and computerized control systems, seed processing plants can now handle large volumes of seeds with minimal human error. Automated systems ensure accurate cleaning, grading, drying, treating, and packaging of seeds, leading to improved productivity and uniformity. This paper discusses the concept, components, benefits, and challenges of automation in seed processing and packaging, highlighting its role in enhancing seed quality and global agricultural sustainability.

Introduction

Seed processing and packaging are critical steps in the seed production chain, ensuring that only high-quality, viable, and pure seeds reach the market. Traditional manual methods, although effective, are time-consuming and prone to inconsistencies. With rapid advancements in agricultural mechanization and digital technologies, automation has emerged as a key innovation to streamline seed processing operations and ensure standardization.

Automation in Seed Processing

Automation in seed processing involves integrating electronic and mechanical systems to perform various seed handling operations. Key automated processes include:

Seed Cleaning and Grading: Optical sorters, sensor and air-screen machines automatically separate seeds based on size, shape, color, and weight, improving uniformity.

Seed Drying: Automated drying systems use temperature and humidity sensors to maintain optimal drying conditions and prevent loss of seed viability.

Seed Treatment: Modern systems apply precise doses of fungicides or insecticides, ensuring uniform coating and minimizing wastage.

Seed Testing: Computerized germination and purity analyzers enable real-time monitoring of seed quality and vigor.

Automation in Seed Packaging

Automated packaging systems ensure accuracy, efficiency, and consistency in filling, sealing,

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and labeling seed containers.

Major technologies use include:

Weighing and Filling Machines: Ensure exact quantities per packet.

Automatic Sealing Systems: Heat sealers and vacuum packers preserve seed quality and extend shelf life.

Robotic Handling Systems: Robots move packaged seeds for labeling, palletizing, and storage.

Barcode and RFID Technology: Enable traceability and monitoring of seed batches throughout the supply chain.

Advantages of Automation

Improved Efficiency: Reduces manual labor and operational time.

Enhanced Accuracy: Ensures precise grading, treatment, and packaging

Consistent Quality: Maintains uniform seed quality across batches.

Traceability: Facilitates monitoring and record-keeping for quality control.

Reduced Losses: Minimizes contamination, human error, and wastage.

Challenges in Automation

High Initial Investment: Installation and maintenance costs can be significant.

Technical Expertise Required: Skilled personnel are needed to operate and maintain systems.

Energy Dependency: Automated systems rely heavily on electricity and stable infrastructure.

Limited Adoption in Developing Regions: Small-scale producers often lack access to automation technologies.

Future Prospects

The future of seed processing and packaging is expected to integrate AI-driven analytics, IoT-based sensors, and machine learning for real-time decision-making and predictive maintenance. Smart automation can lead to fully digitalized seed factories that optimize resources, reduce costs, and support global food security.

Conclusion

Automation in seed processing and packaging enhances seed quality, operational efficiency, and sustainability. While initial costs and technical challenges exist, the long-term benefits make automation an essential component of the modern seed industry. Continued research and adoption of digital technologies will further strengthen the global seed sector.

References

Singh, R. and Sharma, A. (2021). Advancements in Seed Processing Technology. *Journal of Agricultural Engineering*, 58(3): 45-53.

Kumar, P. and Patel, S. (2020). Automation and Digitization in Seed Industry. *Agricultural Mechanization Review*, 12(4): 25-32.

FAO. (2022). Seed processing and quality enhancement technologies. Food and Agriculture Organization of the United Nations.

Mehta, D. and Reddy, G. (2023). Smart automation in seed packaging and distribution systems. *International Journal of AgriTech Innovations*, 9(2): 110-118.

Biochar Enhances Soil Sustainability through Evidence-based Mechanisms and Practice

Archika Awasare

Abstract

Biochar, a multifaceted soil amendment, is rigorously characterised to assess its potential for pollutant removal and its diverse applications. Environmental impact prediction becomes more precise through structural and elemental analyses. The buoyancy in the field of agricultural science was initially a blessing in disguise, but has recently been found to have detrimental consequences. Beyond environmental contamination, the challenges of climate change, fossil fuel depletion, and excessive land degradation have come to the fore. Pollutants such as heavy metals pose a substantial threat due to their persistence in soil and inevitable toxicity to organisms. Considerable efforts have therefore been made to remediate contaminated soils. Biochar possesses a large surface area, strong carbon-sequestration capacity, and abundant nutrient content, with additional potential for bio-oil and syngas production. Consequently, biochar can reduce the bioavailability of pollutants, particularly heavy metals, in soil, contribute to climate-change mitigation through carbon sequestration, and offset fossil-fuel use via bio-oil and syngas production. Further, biochar enhances soil productivity, which can support food security.

Introduction

Globally, biochar, a multipurpose carbonaceous material, is being utilized to enhance soil fertility, alongside improved plant growth and development under both normal and stress conditions. It improves water retention, fosters nutrient absorption, and promotes microbial activity, thereby creating a fertile environment that supports sustainable and resilient agriculture. Biochar also acts as a carbon sink, contributing to long-term carbon sequestration and mitigating climate-change impacts. A major advantage of biochar is its facilitation of adsorption through highly porous structures and diverse functional groups. Understanding the factors involved in biochar formation that determine its characteristics and adsorptive capacity is essential for ensuring its viability in terms of plant productivity and soil health, particularly the biological activity of soils.

From the late eighteenth century onwards, rapid industrialisation transformed socio-economic life, first in Europe and later worldwide. While technological advances increased productivity and comfort, they also produced significant externalities most notably climate change and pollution from heavy metals. Climate change has already affected the planet substantially, and no environmental sphere has remained immune to heavy-metal contamination.

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Once released, heavy metals are transported across air, water, and soil and can persist for long periods. These toxic metals adversely affect plants and animals and degrade ecosystems. It is therefore necessary to pursue remediation strategies that both minimise heavy-metal damage and contribute to climate-change mitigation. Biochar is a carbonaceous product often carbon-neutral or even carbon-negative, obtained via the thermochemical conversion of biomass under oxygen-limited conditions (pyrolysis). The physical and chemical characteristics of biochar vary with pyrolysis temperature and feedstock type. Biochar can reduce the bioavailability and leachability of heavy metals in contaminated soils, improve overall soil quality, and markedly decrease heavy-metal uptake by crops. Furthermore, it can be produced from a wide range of biomass, thereby reducing waste. Recent work highlights its capacity to contribute to climate-change mitigation, produce biofuel, and enhance soil productivity. Accordingly, the application of biochar offers a promising approach not only for remediating contaminated soils but also for addressing climate change, fossil-fuel depletion, and food-security concerns.

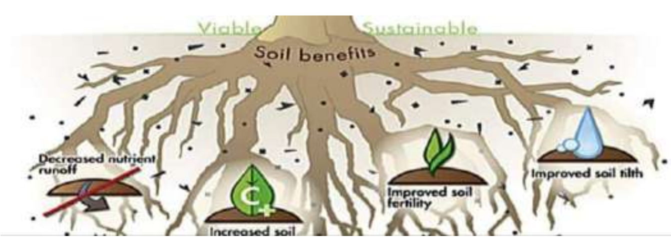

Fig: Benefits of Biochar

Mechanisms Used for the Containment of Pollutants by Biochar

Carbonaceous materials have long been employed as sorbents for contaminants in soil and water. For biochar, the principal mechanisms include:

Sorption (Adsorption/Partitioning): Sorption of organic and inorganic contaminants onto biochar is a key pathway. High surface area, microporosity, pH, and ionic strength influence sorption. Biochar produced at higher pyrolysis temperatures often exhibits greater sorption efficiency for organic-contaminant remediation in soils and water. Adsorption is particularly significant for metallic contaminants.

Hydrogen-Bond Formation: Polar compounds are adsorbed via hydrogen bonds with oxygen-containing surface functional groups on biochar (e.g., carboxyl, hydroxyl, phenolic). In contrast, non-polar compounds associate with hydrophobic sites where hydrogen bonding between water and oxygenated groups is absent.

Electrostatic Attraction/Repulsion: Interactions between positively charged (cationic) organic contaminants and negatively charged biochar surfaces can immobilise pollutants. Electrostatic outer-sphere complexation may occur through metal exchange with K^+ and Na^+ present in the biochar.

Diffusion into Biochar Phases: Non-ionic compounds can diffuse into both the non-carbonised and carbonised fractions of biochar, providing an effective sorption mechanism.

Formation of Surface Complexes: Cations form surface complexes with active functional groups (e.g., –COOH and –OH) on biochar. Generally, metals with smaller ionic radii exhibit greater adsorption capacities.

Precipitation and Co-precipitation: Certain metals (e.g., Pb) can form stable precipitates (such as lead-phosphate-silicates) within or on biochar. Co-precipitation and inner-sphere complexation between metals and the organic matter/mineral oxides in biochar further contribute to immobil-isation.

Sowing Sustainability in Urban Spaces: Horticulture for Resilient Food Systems

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Abstract

Sowing Sustainability in Urban Spaces refers to integrating green practices, particularly horticulture, within city landscapes to promote environmental health, food security, and community well-being. A resilient food system is one that can withstand shocks like climate change, economic disruptions, and urban population growth while ensuring continuous access to nutritious food. Urban horticulture, including rooftop gardens, vertical farming, and community gardens, plays a vital role in building such systems by reducing food miles, recycling urban waste, and increasing local food availability. It also enhances biodiversity, air quality, and social cohesion. By utilizing underused urban areas for food production, horticulture contributes to sustainability and resilience, making cities more self-reliant and adaptive to future challenges. In conclusion, fostering horticulture in urban spaces is a key strategy for cultivating resilient food systems and achieving long-term sustainability in growing metropolitan regions.

Introduction

The global demographic shift, marked by rapid urbanization, is a major 21st-century challenge requiring focused research from the food and nutrition sectors (Khoo and Knorr, 2014). Urbanization, driven by rural-to-urban migration, has led to the rise of megacities and is associated with economic growth and improved living standards but also contributes to poverty, food insecurity, and health disparities (Satterthwaite *et al.*, 2010; Mitlin, 2008). By 2050, over 68% of the global population is projected to reside in urban areas (UN DESA, 2018), intensifying pressure on food systems built for rural models. Urban areas depend on long-distance supply chains vulnerable to disruptions from fuel crises, geopolitical tensions, pandemics like COVID-19, and climate change (FAO, 2020). Limited space and loss of arable land further strain urban food security, especially for low-income groups. Integrating horticulture into urban planning offers a resilient solution, promoting food sovereignty, self-sufficiency, and community resilience, crucial for sustainable urban living.

Urban Horticulture: A Green Solution

Urban horticulture refers to the cultivation of fruits, vegetables, herbs, flowers, and ornamental plants within urban and peri-urban environments. Unlike conventional agriculture, it utilizes unconve-

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ntional spaces such as rooftops, balconies, vacant lots, schoolyards, and community gardens. This practice is gaining prominence due to its capacity to contribute to local food production, environmental sustainability, and community well-being.

According to the Food and Agriculture Organization (FAO, 2022), urban and peri-urban horticulture has the potential to provide up to 20% of a city's fresh food needs. It significantly shortens the food supply chain, reducing transportation energy use and post-harvest losses, while ensuring the availability of fresh and nutritious produce. Practices like rooftop farming, hydroponics, aquaponics, and vertical farming are now being adapted globally to overcome space limitations in cities (Orsini *et al.*, 2013). Urban horticulture also plays a key role in climate action by sequestering carbon, reducing the urban heat island effect, and improving air quality through increased vegetation cover. Additionally, it fosters agro-ecological balance, promotes circular economy models (e.g., composting food waste) and encourages sustainable lifestyles in urban populations.

Resilience through Local Food Systems: Local food systems, particularly those supported by urban and peri-urban horticulture, play a vital role in strengthening a city's resilience against food insecurity, supply chain disruptions, and climate-induced shocks. These systems prioritize shorter supply chains, community-based food networks, and localized production, all of which enhance the reliability and flexibility of urban food access. A resilient food system is one that can absorb shocks, adapt to changes, and continue to function effectively during crises. During the COVID-19 pandemic, cities with strong local food systems, such as community-supported agriculture (CSA) or urban gardens, demonstrated higher levels of food access and security (Tendall *et al*., 2015; FAO, 2020). These systems reduce reliance on distant suppliers and volatile global markets, thereby cushioning cities from external disruptions. Moreover, local food systems often operate on sustainable ecological principles, such as organic production, composting, rainwater harvesting, and biodiversity enhancement. They also serve as social safety nets, enabling marginalized groups to participate in food production and empowering communities through collective action. Integrating local food systems into urban policy and planning can also address issues of social equity, nutrition, and environmental sustainability, making cities more livable and self-reliant in the long term.

Innovations Driving Urban Horticulture: Technological innovations are transforming urban horticulture into a space-efficient, resource-optimized, and sustainable food production system, enabling higher yields in limited spaces and seamless integration into urban infrastructure.

- ✓ **Smart and Precision Technologies:** Internet of Things (IoT)-based sensors monitor soil moisture, temperature, and nutrient levels in real time, enabling precise irrigation and fertilization. Automated irrigation systems reduce water use by delivering the right amount of water at the right time.

- ✓ **Vertical and Modular Farming:** Vertical farming utilizes stacked layers of crops in controlled environments, allowing food to be grown in warehouses, shipping containers, or even skyscrapers. Modular hydroponic systems enable small-scale urban farmers to grow leafy greens and herbs without soil, using nutrient-rich water solutions (Despommier, 2010).
- ✓ **Sustainable Practices:** Use of organic inputs, such as composted urban waste and biofertilizers, promotes ecological balance. Adoption of recycled containers and upcycled materials for planters reduces plastic use and promotes circular economy models.
- ✓ **Data and Artificial Intelligence (AI):** AI tools assist in predicting plant health issues, optimizing harvest times, and maximizing yields. Integration of mobile apps and dashboards allows urban gardeners to manage their gardens remotely.

Benefits of Urban Horticulture: Urban horticulture delivers diverse environmental, social, economic, and educational benefits, making it vital for sustainable, inclusive cities. It reconnects people with nature and transforms underused urban spaces into productive green landscapes as cities continue to expand.

Economic Benefits	Urban horticulture lowers household food costs, creates green jobs and promotes entrepreneurship through local markets and value-added products, contributing to economic empowerment and sustainable urban livelihoods.
Environmental Benefits	Urban horticulture supports sustainable city living by reducing carbon emissions from food transport, mitigating the urban heat island effect, improving air quality, and enhancing biodiversity. It also promotes circular resource use through composting and greywater irrigation, boosting urban resilience (de Zeeuw *et al.*, 2011).
Social Benefits	Urban horticulture enhances social and psychological well-being by fostering community through shared gardens, improving mental health via green space interaction (Soga *et al.*, 2017), and offering therapeutic, recreational benefits, especially for the elderly and children through engaging, nature-based activities.
Educational Benefits	Urban horticulture serves as an effective educational platform, promoting awareness and understanding of sustainability, nutrition, ecology, and agriculture. It encourages youth engagement through hands-on learning experiences, fostering a strong sense of environmental stewardship and responsibility among the next generation.

Challenges and the Way Forward

While urban horticulture holds significant promise for sustainable and resilient food systems, several barriers and limitations continue to hinder its full-scale adoption. Addressing these challenges is crucial for mainstreaming urban farming as an essential part of city planning and development.

Key Challenges: Despite its benefits, urban horticulture faces challenges like limited and costly space, water scarcity, and inadequate structural support for cultivation (de Zeeuw *et al.,* 2011). A lack of supportive policies, urban planning, and public awareness further hinders its adoption (RUAF Foundation, 2016). Additionally, many lack the skills or resources to start urban gardens, while advanced systems like hydroponics remain costly and require ongoing maintenance.

The Way Forward: Promoting urban horticulture requires strategic actions such as integrating it into urban planning, offering policy incentives, and fostering education through training and awareness programs. Public-private partnerships can enhance access to resources, while adopting circular economy practices like composting and greywater use ensures cost-effective, environmentally sustainable urban food production (Dubbeling *et al*., 2010).

Conclusion: Cultivating Change

As urbanization transforms global cities, rethinking food production is essential. Urban horticulture offers a sustainable, resilient, and innovative solution, turning rooftops, balconies, and community spaces into sources of fresh food, improved nutrition, and ecological stewardship. The COVID-19 pandemic, climate crises, and urban poverty highlight the urgent need to evolve traditional food systems (FAO, 2020). To scale this transformation, inclusive policies, education, partnerships, and civic engagement are crucial. Empowering youth and marginalized communities to grow food locally can reshape urban food systems. Urban horticulture not only cultivates crops, it cultivates hope, resilience, and a self-reliant urban future (FAO, 2020).

References

Despommier, D. (2010). The vertical farm: feeding the world in the 21st century. Macmillan.

Dubbeling, M., Zeeuw, H. D. and Veenhuizen, R. V. (2010). Cities, poverty and food: multi-stakeholder policy and planning in urban agriculture (pp. 152-pp).

De Zeeuw, H., Van Veenhuizen, R. and Dubbeling, M. (2011). The role of urban agriculture in building resilient cities in developing countries. *The Journal of Agricultural Science*, 149(S1): 153-163.

FAO. (2022). Urban and Peri-Urban Agriculture Sourcebook - From Production to Food Systems. Food and Agriculture Organization of the United Nations. https://www.fao.org

Food and Agriculture Organization of the United Nations (FAO). (2020). Urban food systems and COVID-19: The role of cities and local governments in responding to the emergency. https://doi.org/10.4060/ca8600en

Khoo, C. S. and Knorr, D. (2014). Grand challenges in nutrition and food science technology. *Frontiers of Nutrition*, 1: 4.

Mitlin, D. (2008). With and beyond the state co-production as a route to political influence, power and transformation for grassroots organizations. *Environmental Urbanization*, 20: 339-60.

Orsini, F., Kahane, R., Nono-Womdim, R. and Gianquinto, G. (2013). Urban agriculture in the developing world: a review. *Agronomy for Sustainable Development*, 33(4): 695-720.

Tendall, D. M., Joerin, J., Kopainsky, B., Edwards, P., Shreck, A., Le, Q. B., Krütli, P., Grant, M. and Six, J. (2015). Food system resilience: Defining the concept. *Global Food Security*, 6: 17-23.

RUAF Foundation. (2016). *Urban Agriculture and Food Systems: Sourcebook*. http://www.ruaf.org

Satterthwaite, D., McGranahan, G. and Tacoli, C. (2010). Urbanization and its implications for food and farming. *Philos Trans R Soc Lond B Biological Sciences*, 365: 2809-20.

Soga, M., Gaston, K. J. and Yamaura, Y. (2017). Gardening is beneficial for health: A meta-analysis. *Preventive Medicine Reports*, 5: 2-99.

United Nations, Department of Economic and Social Affairs (UN DESA). (2018). World Urbanization Prospects: The 2018 Revision. https://population.un.org/wup/

Chromosomes and Chromosomal Disorders

N. Shivananthini, S. Subhashini and K. Cholan

Abstract

Chromosomes are essential carriers of genetic information, determining an individuals traits, development, and overall health. Each human cell typically contains 46 chromosomes arranged in 23 pairs. Any alteration in their number or structure can lead to chromosomal disorders, which may result in physical, developmental, or intellectual challenges. This article provides an overview of chromosomes, explains the causes and types of chromosomal disorders such as Down syndrome, Turner syndrome, and structural anomalies and highlights the importance of early diagnosis and genetic counselling. Understanding these disorders is vital for improving awareness, healthcare support, and advancing genetic research.

Introduction

Microscopic thread-like structures called chromosomes. They carry the genetic code that determines everything from your eye color to your height and even your health.

Chromosomes

Chromosomes are long strands of DNA packed inside the nucleus of every cell in your body. Think of them as tiny instruction manuals that guide how your body grows, functions, and looks. Humans have 46 chromosomes arranged in 23 pairs. One set comes from your mother, and one from your father. The 23rd pair determines your sex: XX for females and XY for males. Each chromosome contains thousands of genes which are specific sections of DNA that code for traits like blood type, hair texture, and much more.

Chromosomal Disorders

Chromosomal disorders occur when there is a change in the number or structure of chromosomes. These changes can cause mild to severe physical and intellectual disabilities, depending on the type of disorder. They usually happen due to errors during cell division especially when egg or sperm cells are formed.

Types of Chromosomal Disorders

Numerical Disorders: Occur when there are too many or too few chromosomes. Example: Down Syndrome (Trisomy 21) Caused by an extra copy of chromosome 21. Leads to developmental delays, intellectual disability, and distinct facial features.

Turner Syndrome (XO) Affects females who

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have only one X chromosome instead of two. Results in short stature, delayed puberty, and infertility.

Klinefelter Syndrome (XXY) Affects males with an extra X chromosome. May cause reduced testosterone and learning difficulties.

Structural Disorders: Occur when a part of a chromosome is missing, duplicated, or rearranged. Example: Cri-du-chat Syndrome Caused by deletion of a part of chromosome 5. Named after the high-pitched, cat-like cry of affected infants.

Importance of chromosomes

- ✓ It helps diagnose and manage genetic diseases.
- ✓ It improves awareness of reproductive health.
- ✓ It supports research into treatments and therapies.

Conclusion

Chromosomes may be invisible to the eye, but they hold the blueprint of life. While most people have a perfect set of 46, even the smallest mistake can lead to significant changes. Understanding chromosomal disorders not only builds awareness but also opens doors to compassion, support, and scientific progress.

References

Griffiths, A. J. F., Wessler, S. R., Carroll, S. B. and Doebley, J. (2019). Introduction to Genetic Analysis (12th ed.). W.H. Freeman and Company.

Nussbaum, R. L., McInnes, R. R. and Willard, H. F. (2015). Thompson & Thompson Genetics in Medicine (8th ed.). Elsevier Health Sciences.

World Health Organization (WHO). (2021). Genetic Disorders. Retrieved from www.who.int

National Human Genome Research Institute (NHGRI). (2020). Chromosomal Disorders Fact Sheet. Retrieved from www.genome.gov

Mayo Clinic. (2023). Genetic conditions and chromosomal disorders. Retrieved from www.mayoclinic.org

Organic Matter: The Heartbeat of Soil Fertility

M. A. Ajabe and N. M. Maske

Abstract

Soil organic matter (SOM) is a critical component of healthy soils, acting as the foundation of soil fertility and ecosystem sustainability. Composed of decomposed plant and animal residues, microbial biomass and humus, organic matter improves soil structure, enhances water retention and promotes nutrient cycling. It provides a reservoir of essential nutrients such as nitrogen, phosphorus and sulphur, supporting plant growth and productivity. Beyond fertility, SOM plays a pivotal role in mitigating climate change by sequestering carbon and reducing greenhouse gas emissions. Its presence fosters a diverse microbial community, which drives soil enzymatic activity and overall soil resilience against degradation. Modern agricultural practices, including crop rotation, cover cropping and organic amendments, are essential to maintain and enhance soil organic matter levels. Understanding and managing SOM is therefore fundamental for sustainable agriculture, environmental health and long-term food security.

Introduction

Soil is much more than a medium to anchor plants it is a dynamic ecosystem that sustains life on Earth. At the core of this system lies soil organic matter (SOM), often called the "heartbeat of soil fertility." Organic matter is composed of decomposed plant and animal residues, microbial biomass and stable humus. It plays a vital role in maintaining soil health by improving structure, increasing water holding capacity and enhancing nutrient availability. Organic matter acts as a reservoir of essential nutrients such as nitrogen, phosphorus and sulphur, gradually releasing them to plants and supporting sustained crop growth.

Beyond its direct contribution to fertility, SOM fuels soil microbial activity, fostering a diverse community of bacteria, fungi and other micro-organisms that drive nutrient cycling and soil resilience. Healthy organic matter levels also help combat soil erosion, buffer pH and mitigate the impacts of climate change through carbon sequestration. Unfortunately, intensive agriculture, deforestation and overuse of chemical fertilizers have led to declining organic matter in many soils, threatening productivity and ecosystem balance. Understanding the role of organic matter and adopting practices to maintain or enhance it is therefore critical for sustainable agriculture, environmental protection

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and global food security.

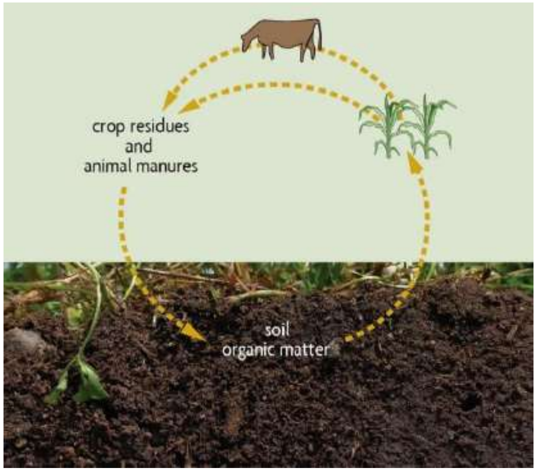

Fig. 1: Organic Matter: The Heartbeat of Soil Fertility

Content of Topic

Organic Matter: The Heartbeat of Soil Fertility:

Soil is not merely a collection of minerals it is a living system that breathes, grows and sustains life. At the center of this dynamic system lies soil organic matter (SOM), often referred to as the heartbeat of soil fertility. It is the key indicator of soil health, productivity and sustainability. Organic matter consists of plant and animal residues at various stages of decomposition, microbial cells and tissues and humus the dark, stable fraction that gives soil its characteristic color and fertility.

Importance and Functions of Soil Organic Matter : Organic matter plays multiple roles in maintaining soil quality. It improves soil structure, making it crumbly and porous, which enhances aeration and root penetration. It increases the water-holding capacity of sandy soils and improves drainage in clayey soils. More importantly, organic matter acts as a reservoir of essential nutrients such as nitrogen (N), phosphorus (P), and sulfur (S), which are slowly released through microbial decomposition, ensuring a continuous nutrient supply to plants. SOM also serves as a source of energy and food for soil micro-organisms. These microbes break down organic materials, releasing enzymes that drive vital processes like mineralization, nitrification and humification. A thriving microbial population enhances nutrient cycling and disease suppression, contributing to long-term soil fertility and plant health.

Soil Organic Matter and Carbon Sequestration:

Beyond agriculture, soil organic matter plays a crucial role in the global carbon cycle. Nearly two-thirds of the carbon stored in terrestrial ecosystems resides in soils. By capturing atmospheric carbon dioxide (CO_2) through plant residues and storing it in the form of humus, soils act as a carbon sink**.** This process, known as carbon sequestration, helps mitigate the effects of climate change by reducing greenhouse gas concentrations. Maintaining or increasing SOM through sustainable practices is therefore essential for environmental stability and climate resilience.

Decline of Organic Matter: Causes and Consequences: Despite its importance, organic matter levels in soils are declining worldwide due to unsustainable agricultural practices. Intensive tillage**,** mono-cropping and the overuse of chemical fertilizers accelerate the decomposition of organic carbon and reduce soil biological activity. Deforestation and overgrazing further deplete organic inputs, leading to soil erosion and degradation. As SOM declines, soil structure deteriorates, water infiltration decreases and nutrient retention weakens.

Management Practices to Enhance Soil Organic Matter

Rebuilding and maintaining soil organic matter requires an integrated and long-term appr-oach. The following practices are widely recommended:

Addition of Organic Amendments: Application of farmyard manure, compost, green manure and crop residues enriches soil with fresh organic inputs.

Reduced Tillage: Minimizing soil disturbance slows down organic matter oxidation and preserves soil aggregates.

Crop Rotation and Cover Cropping: Diverse cropping systems and cover crops enhance biomass production and microbial diversity.

Agroforestry and Conservation Agriculture: Integrating trees and maintaining ground cover reduces erosion and improves carbon storage.

Balanced Fertilization: Combining organic and inorganic nutrient sources maintains productivity while supporting soil life.

Adopting these practices helps sustain soil fertility, enhance biodiversity, and improve overall soil health.

Conclusion

Soil organic matter is truly the *heartbeat* of soil fertility and a cornerstone of sustainable agriculture. It integrates physical, chemical and biological functions that determine the productivity and ecological balance of soils.

Protecting and replenishing SOM is not just a scientific necessity but a moral responsibility essen-tial for food security, environmental conservation and climate change mitigation. As farmers, researchers, and policymakers work together to promote organic matter management, they are not only nurturing fertile soils but also securing the foundation of life on Earth.

References

Brady, N. C. and Weil, R. R. (2017). The Nature and Properties of Soils (15th ed.). Pearson Education.

FAO. (2017). Soil Organic Carbon: The Hidden Potential. Food and Agriculture Organization of the United Nations, Rome.

Six, J., Conant, R. T., Paul, E. A. and Paustian, K. (2002). Stabilization mechanisms of soil organic matter: Implications for C-saturation of soils. *Plant and Soil*, 241(2): 155-176.

Lal, R. (2020). Managing soil organic carbon for climate change mitigation and adaptation in smallholder farming. *Global Food Security,* 26: 100377.

Stevenson, F. J. (1994). *Humus Chemistry: Genesis, Composition, Reactions* (2nd ed.). John Wiley & Sons.

Hydroponics: The Art of Soil-less Production System

Roshan Jadhav

Introduction

The term 'Hydroponics' was derived from the Greek words '*hydro*' means water and '*ponos*' means labour. It is the technique of growing plants using mineral nutrients solution. In this technique, plants are growing in soil-less conditions and their roots are immersed in nutrients solution. Reports revealed that hydroponic activities linked from 4000 years back. However, plant biology research associated with hydroponic started from 1929. Then after commercial crop production via nutrient solution began by William Frederick Gericke from the University of California at Berkeley, and the other hydroponic systems developed subsequently. Now a days commercial cultivation via hydroponics is being conducted at a greater extent in agricultural and horticultural crop production, along with it has greater significance towards plant biology researches. Considering its efficiency, capability of modification and possibility of its development, the use of hydroponic systems cannot be unavoidable for plant biology researchers.

Advantages of conducting plant agricultural research in hydroponics

- ✓ Management of plant nutrients is very convenient.
- ✓ Nutrients can be directly available to plants.
- ✓ Easily controls its P^H and EC.
- ✓ Mutual elements interactions can be easily monitored.
- ✓ Less chance of soil-borne diseases or pests attack.
- ✓ Less water requirement than the soil culture.
- ✓ Roots are visible, and the root zone environment is easily monitored.
- ✓ Little or no pesticide is required.
- ✓ Plants can be grown in both on and off-seasons.
- ✓ Plants grow up to 50% faster than in soil.
- ✓ Higher number of plants can be grown in a small area.

Types of liquid hydroponics

- ✓ Nutrient film technique (NFT)
- ✓ Deep floating technique (DFT)
- ✓ Root Dipping Technique (RDT)
- ✓ Capillary Action Technique (CAT)

Hydroponic Structures and their Operation

Hydroponic system are customised and modified according to recycling and reuse of nutrient solution and supporting media.Commonly used systems are wick, drip, ebb-flow, deep water culture and nutrient film technique (NFT) which are described below.

Wick System: This is simplest hydroponic system requiring no electricity, pump and aerators. Plants are placed in an absorbent medium like coco coir, vermiculite, perlite with a nylon wick running from

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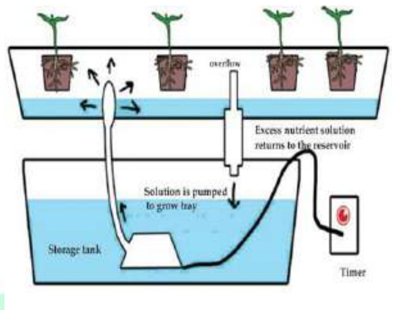
plant roots into a reservoir of nutrient solution. Water or nutrient solution supplied to plants through capillary action. This system works well for small plants, herbs and spice and doesn't work effectively that needs lot of water.

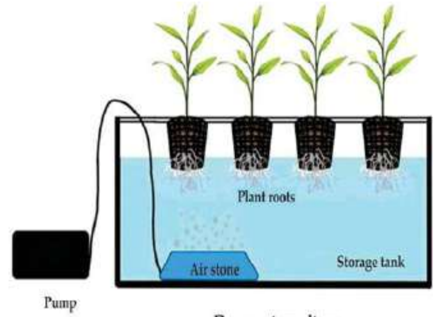
Ebb and Flow system: This is first commercial hydroponic system which works on the principle of flood and drain. Nutrient solution and water from reservoir flooded through a water pump to grow bed until it reaches a certain level and stay there for certain period of time so that it provide nutrients and moisture to plants. Besides, it is possible to grow different kinds of crops but the problem of root rot, algae and mould is very common (Nielsen *et al.*, 2006) therefore, some modified system with filtration unit is required.



Ebb & Flow System

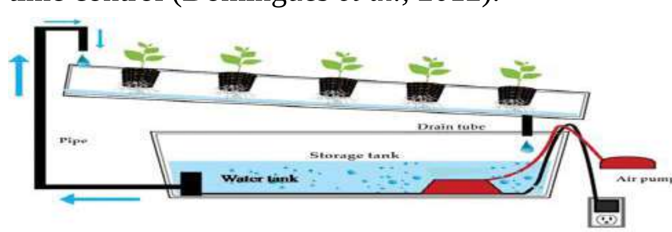
Drip system: The drip hydroponic system is widely used method among both home and commercial growers. Water or nutrient solution from the reservoir is provided to individual plant roots in appropriate proportion with the help of pump (Rouphael and Colla, 2005). Plants are usually placed in moderately absorbent growing medium so that the nutrient solution drips slowly. Various crops can be grown systematically with more conservation of water.

Deep water culture system: In deep water culture, roots of plants are suspended in nutrient rich water and air is provided directly to the roots by an air stone. Hydroponics buckets system is classical example of this system. Plants are placed in net pots and roots are suspended in nutrient solution where they grow quickly in a large mass. It is mandatory to monitor the oxygen and nutrient concentrations, salinity and pH (Domingues *et al.*, 2012) as algae and moulds can grow rapidly in the reservoir. This system work well for larger plants that produce fruits especially cucumber and tomato, grow well in this system.



Deep water culture

Nutrient Film Technique (NFT) system: NFT was developed in the mid 1960s in England by Dr. Alen Cooper to overcome the shortcomings of ebb and flow system. In this system, water or a nutrient solution circulates throughout the entire system; and enters the growth tray via a water pump without a time control (Domingues *et al.*, 2012).



NFT (Nutrient Film Technique)

The system is slightly slanted so that nutrient solution runs through roots and down back into a reservoir. Plants are placed in channel or tube with roots dangling in a hydroponic solution. Although, roots are susceptible to fungal infection because they are constantly immersed in water or nutrient.

In this system, many leafy green can easily be grown and commercially most widely used for lettuce production.

Role in agricultural research

Hydroponic techniques have been used in several aspects of plant biology researches such as plant nutrition, heavy metals toxicity, identification of elements deficiency, screening for abiotic stresses, screening for aluminium toxicity, root functions, root anatomy and in many more.

Plant nutrition

- ✓ Soil-less methodology is using extensively from middle of twenty century in plant nutrition research. Numbers of research were conducted in hydroponics and the results of those experiments based on the nutrition solutions where the plants were grown are considered as soil. The proper condition in hydroponic solution is maintained by P^H, EC and presence or absence of some elements is monitoring nutrients uptake during the plant nutrition researches.

Table 1: Optimum range of EC and pH values for hydroponic crops

Crops	EC (dS m^{-1})	pH
Asparagus	1.4 to 1.8	6.0 to 6.8
Bean	2.0 to 4.0	6.0
Banana	1.8 to 2.2	5.5 to 6.5
Broccoli	2.8 to 3.5	6.0 to 6.8
Cabbage	2.5 to 3.0	6.5 to 7.0
Celery	1.8 to 2.4	6.5
Carnation	2.0 to 3.5	6.0
Cucumber	1.7 to 2.0	5.0 to 5.5
Egg plant	2.5 to 3.5	6.0
Lettuce	1.2 to 1.8	6.0 to 7.0
Parsley	1.8 to 2.2	6.0 to 6.5
Rose	1.5 to 2.5	5.5 to 6.0
Spinach	1.8 to 2.3	6.0 to 7.0
Strawberry	1.8 to 2.2	6.0
Tomato	2.0 to 4.0	6.0 to 6.5

- ✓ Hydroponics provides suitable environments to detect the individual effects of elements on quantity and yield quality. (e.g: Many reports showed that influences of potassium on yield qualitative attributes sulfate in root zone are responsible for growth and elevation of micro and macro elements absorption.
- ✓ Tracing of nutrients in plants and comparison between plants on the basis of nutrient absorption has been studied since last decade by radiocesium in the hydroponics system.
- ✓ Hydroponics studies were conducted to study nutrient use efficiency, deficiency effects of micro and macronutrients and effects of interaction of different nutrients on crop plants.

Allelopathy in the rhizosphere

- ✓ Effect of allelopathy studies need to identify chemical procedures, biologically active substances and the phytotoxic potential is quite difficult in field conditions.
- ✓ Hydroponics is a proper method to identify quantitative and qualitative determination of allelopathic materials and procedure of interaction between allelopathic materials with other chemical compound.
- ✓ The allelopathy compounds and screening the grain crops developed a fast and consistent bioassay method. The bioassay carried out in hydroponics culture, and a range of experiments with 2-(3H)-benzoxazolinone, an allelochemical of several grain crops, was carried out to define the basic protocol.

Abiotic stresses

- ✓ The use of hydroponics system for studying the abiotic stresses such as salinity and drought stresses is beneficial; help to understand abiotic tolerant mechanisms and identify abiotic stress-inducible genes in the tolerant plants.
- ✓ For screening of abiotic stresses tolerant plants, hydroponic methods provide suitable conditions to achieve proper data relevant to physiological and biochemical responses such as chlorophyll contents and photosynthesis rate, stomatal conductance, transpiration rate, proline concentration, K/Na ratio, antioxidative enzymes activities etc.
- ✓ Effects of drought stress on rice genotypes in hydroponic method was more clearly observed.

Plant roots

- ✓ Hydroponics is an ideal method for observing the root growth and development over time in different conditions.
- ✓ It is a convenient method to study the root morphology, anatomy, and root/shoot ratio, nutrient deficiencies, enzymatic activities, of the roots, root exudates, microorganisms activities in the rhizosphere and the effects of toxic elements on roots.
- ✓ It is an ideal method for observing root architecture and finding its relationship to plant productivity.

Heavy metal

- ✓ Hydroponics can be used to identify and characterize the mechanisms of tolerance to excess heavy metals in plants.
- ✓ It is the only way of eliminating mass transfer limitations and elucidating free metal ion and uptake and translocation of metal-chelate within the plant.
- ✓ In hydroponic and soil experiments, 'As' and 'Cd' showed synergetic and antagonistic effects on wheat root elongation.
- ✓ Hydroponically grown plants such as Indian mustard (*B. juncea* L.) and Sunflower (*H. annuus* L.) can extract the toxic metals like, Pb, Cu, Cr, Cd, Zn, and Ni, from aqueous solutions efficiently.

Aluminium toxicity

- ✓ Although Aluminum (Al) is not an essential element, its low concentration can increase plant growth. 'Al' toxicity is one of the most common limiting factors for plants grown in acid soils. Excess 'Al' interrupts cell division in roots, increases the cell wall rigidity, fixes phosphorous in soils, reduces root respiration, interferes with uptake, transport and use of several essential elements such as Ca, Mg, K, Fe and P.
- ✓ Stress tolerance is genetically controlled, screening and selecting of Al tolerant genotypes under hydroponically, lead to improving tolerant cultivars to excess 'Al' because hydroponics provides easy access to root system, exact control over available nutrients and PH and non-destructive measurements of tolerance.

Conclusion

There are several advantages to conduct

research related to agriculture in hydroponics as maintenance of P^H, EC, concentration of macro and microelements in hydroponics system is easy. So, it has greater importance to study plant nutrition, allelopathy effects, abiotic stresses, plant roots, heavy metal, aluminium toxicity through hydroponics technique.

References

Cramer, G. R., Urano, K., Delrot, S., Pezzotti, M. and Shinozaki, K. (2011). Effects of abiotic stress on plants: A systems biology perspective. *BMC Plant Biology*.

Domingues, D. S., Takahashi, H. W., Camara, C. A. P. and Nixdorf, S. L. (2012). Automated system developed to control pH and concentration of nutrient solution evaluated in hydroponic lettuce production. *Computers and Electronics in Agriculture*, 84: 53-61.

Nielsen, C. J., Ferrin, D. M. and Stanghellini, M. E. (2006). Efficacy of biosurfactants in the management of *Phytophthora capsici* on pepper in recirculating hydroponic systems. *Canadian Journal of Plant Pathology*, 28(3): 450-460.

Sambo, P., Nicoletto, C., Giro, A., Pii, Y., Valentinuzzi, F., Mimmo, T., Lugli, P., Orzes, G., Mazzetto, F., Astolfi, S., Terzano, R. and Cesco, S. 2019. Hydroponic Solutions for Soilless Production Systems: Issues and Opportunities in a Smart Agriculture Perspective. *Frontiers in Plant Science*.

Rouphael, Y. and Colla, G. (2005). Growth, yield, fruit quality and nutrient uptake of hydroponically cultivated zucchini squash as affected by irrigation systems and growing seasons. *Scientia Horticulturae*, 105(2): 177-195.

Direct Seeded Rice: A Sustainable Revolution in the Fields of South Asia

Siddhant Kumar Pundir

The Changes in Rice Farming

Farmers in South Asia's rice paddies are at a crossroads. Rice is more than simply sustenance there; it's a way of life. The traditional way of farming rice, which involves planting seedlings in flooded fields that were raised in nurseries, has long been the main way to keep food safe in the area. But today, this system is under more and more pressure since there aren't enough workers, the groundwater is running out, and the weather is changing. In this situation, a method called Direct Seeded Rice (DSR) is becoming increasingly popular because it is simpler and more environmentally friendly. Direct Seeded Rice (DSR) is different from transplanting since it skips the nursery and puddling processes and plants seeds straight in the field. This method of growing rice is a big change for a region that relies heavily on rice and has less resources. It might have big effects on production, sustainability, and the livelihoods of farmers.

Why Farmers Are Choosing Direct Seeding

One of the best things about DSR is that it can save water. A kilogram of rice grown in traditional puddled rice fields needs between 3,000 and 5,000 gallons of water. In places like Punjab and Haryana, where groundwater levels are dropping quickly, it is becoming harder and harder to keep doing things this way. DSR can save up to 40% of water, which is a lifesaver for areas that are already having trouble with water. Another reason to buy is that it saves labor. Transplanting takes a lot of work and needs to be done at the right time during busy times. People are moving to cities more and more, while rural populations are getting older. This makes it hard to find work. With DSR, farmers may use machines to plant seeds, which means they don't need as many field laborers and can plan their work more freely. There are additional benefits for the environment. Rice paddies that are flooded are known for releasing methane, which is a greenhouse gas that is stronger than carbon dioxide. Because DSR has less standing water, it releases a lot less methane, which is in line with the goals of climate-smart agriculture. Also, DSR crops usually develop about a week earlier than transplanted ones. This gives farmers additional options for crop rotation, so they can grow wheat, mustard, or vegetables in the same season.

Types of DSR

Direct Seeded Rice (DSR) can be broadly classified into three main types based on soil and water management practices: Dry DSR, Wet DSR, and Water-Seeded DSR. In Dry DSR, seeds are sown directly into dry or moist, non-puddled soil using a seed drill before the onset of monsoon rains, making it suitable for rainfed and irrigated upland areas. Wet DSR, also known as Wet-Tilled DSR (WTD DSR),

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involves sowing pre-germinated seeds into puddled and saturated soil, often used in lowland conditions where continuous water supply is available. Water-Seeded DSR is practiced mainly in deep-water or flood-prone areas, where seeds are broadcast into standing water. Additionally, the Alternate Wetting and Drying (AWD DSR) system integrates intermittent irrigation, allowing the soil to dry periodically between irrigations, thereby improving water-use efficiency and reducing methane emissions. Each DSR type offers unique benefits depending on soil texture, water availability, and climatic conditions, making DSR a versatile and sustainable alternative to traditional transplanted rice (TPR) systems.

New Issues in a New System

Even while DSR has some good points, it is not a magic bullet. One of the main difficulties is weed management. When fields are inundated, standing water naturally stops weeds from growing. With DSR, both rice and weeds sprout at the same time, which makes fields more open to invading species. This makes farmers use more herbicides, especially those that work before and after plants grow. This raises prices and raises worries about the long-term effects on health and the environment. DSR also needs the right amount of water and soil pretreatment. When fields aren't level or the moisture levels aren't stable, uneven germination is a regular concern. Bad crop stands can lower yields and make areas more likely to get pests. Also, DSR's benefits may not be as great in some types of heavy soils or areas with poor drainage unless more work is done in the field or money is spent on infrastructure.

In DSR systems, managing pests and diseases also changes. Some pests, such as stem borers and rodents, may become more common when seeds are left out in the open for prolonged periods of time. On the other hand, diseases like blast may get worse in DSR areas that aren't well cared for. All of this means that training, technical help, and close observation are all necessary for successful adoption.

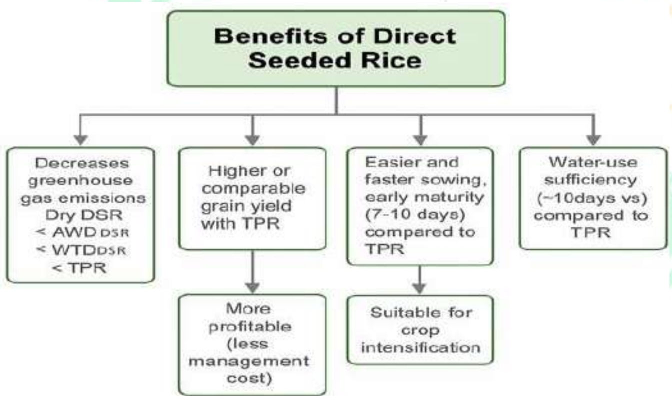
The Tools That Make DSR Work

Fortunately, a number of new technologies and farming methods are helping to solve these problems.For example, laser land leveling is becoming more widespread, especially in India. It makes sure that the fields are even, which helps with even germination and good water distribution. People are also using precision seeding machines, including zero-till drills, to sow seeds at the right depths and distances. This is really important for DSR to work.

While herbicide use is still a problem, it is becoming more focused and effective. If used correctly and at the right time, products like pendimethalin and bispyribac-sodium can make weeds much less of a problem. Researchers are also focusing on integrated weed management tactics that use chemical, mechanical, and biological methods together to cut down on the need for herbicides. Digital technologies are also helping. Farmers may now make decisions in real time with mobile apps and advisory systems. These decisions range from when to water crops to how to deal with pest outbreaks. These technologies are especially helpful in areas where extension agencies don't have enough money or staff.

Adapting to a climate that is changing

Farming systems need to evolve as climate change speeds up. DSR is good for the climate because it cuts down on water use and emissions, which are both vital in a world that is getting warmer. Farmers may also respond better to changes in the weather with this strategy. Because DSR doesn't depend on transplanting, planting windows are more flexible, which helps farmers deal with monsoons that come late or don't happen at all.



A big example happened in 2020, when the COVID-19 epidemic hit. Many Indian farmers have to turn to DSR because of a lack of workers and problems with transportation. That year, the DSR area in Punjab tripled. Many farmers said they were happy with the yields and cost savings they got from the change, even though it wasn't easy to make the switch. For a lot of people, it was proof that DSR could be more than simply a way to deal with an emergency; it might be the way things will be in the future.

Policy Support and Involvement of Farmers

Some government programs are starting to see the possibilities of DSR. In India, especially in Punjab and Haryana, people are increasingly being offered money to switch to DSR. Subsidies for tools for planting seeds and controlling weeds are making it easier for people to get started. In addition, agricultural colleges and Krishi Vigyan Kendras are holding training seminars and demonstration plots to teach farmers how to get the most out of DSR. These initiatives do need to be bigger and more focused, though. A lot of small and marginal farmers still can't afford to buy equipment or pay for herbicides and training. Without laws that include everyone, the benefits of DSR may stay with the bigger landowners who can afford to make the change. If DSR is going to really change how rice is grown on a large basis, this gap needs to be closed.

Breeding, Research, and What's Next

Crop breeding and agronomic research are the next big steps in DSR growth. Scientists are also working on creating rice cultivars that are particular to DSR. These plants will have robust early growth, be able to survive dry spells, and be able to compete with weeds. The International Rice Research Institute (IRRI) and India's ICAR are two groups that are at the forefront of these initiatives. Researchers are also looking on biological weed control, better crop rotation methods, and the long-term effects of using herbicides on the environment. At the same time, new businesses are coming up with AI-powered decision-making tools, automated irrigation systems and data-driven farm management platforms that are made just for DSR's needs. DSR could also be a very important new idea for countries in Southeast Asia and Sub-Saharan Africa, where small farmers confront the same problems with water, labor, and soil degradation that they do in South Asia. Sharing knowledge, working together in the region, and using different types of seeds could all help this movement go global.

A Future Based on Sustainability

Direct Seeded Rice is more than just a way to farm; it's a way to deal with the problems that modern farming is facing right now. DSR could change rice farming into a more sustainable, resilient, and farmer-friendly system since it can save water, cut down on greenhouse gas emissions, and lower prices. Of course, there will be problems during any change. But with the appropriate mix of government assistance, training for farmers, new technologies, and long-term study, DSR might help create a new method to grow rice. One that is good for the environment, helps people make a living, and changes with the weather.

The seeds of this change are already being planted in the huge rice fields of South Asia. The next step is to take care of them together, carefully, and with a plan.

Smart Horticulture: Revolutionizing Crop Production with Technology and Innovation

Anju Yadav and Rupa Ujjwal

Smart horticulture practices leverage cutting-edge technologies and innovative methods to enhance crop yields, reduce waste, and promote sustainability in agriculture. By integrating precision farming, vertical farming, hydroponics, and IoT-enabled monitoring systems, farmers and growers can optimize growing conditions, reduce resource consumption, and improve crop quality and explores the need for smart horticulture practices, highlights various techniques and technologies used, and discusses the benefits and future directions of this rapidly evolving field.

Why Smart Horticulture Practices are Needed

The global population is projected to reach 9.7 billion by 2050, putting pressure on the agricultural sector to produce more food while minimizing environmental impact. Smart horticulture practices address this challenge by:

Increasing crop yields: Through precision farming and optimized growing conditions.

Reducing resource consumption: By using hydroponics, vertical farming and efficient irrigation systems.

Improving crop quality: With advanced monitoring and control systems.

Enhancing sustainability: By promoting eco-friendly practices and reducing waste.

Smart Horticulture Practices

Artificial Intelligence (AI) and Machine Learning (ML): Analyzes data to predict crop yields, detect diseases, and optimize growing conditions.

Precision Farming

Precision farming, also known as precision agriculture, is an agricultural practice that uses advanced technology by collect real time data on various aspects of environment to optimize crop yields and reduce waste. It involves using:

Sensors: To monitor soil moisture, temperature, and plant health in field or greenhouse.

Drones: To capture aerial images of crops, detect issues, and apply targeted treatments.

GPS: To track equipment and monitor crop yields.

Data analysis: To analyze data from sensors, drones, and other sources to make informed decisions.

Benefits of precision farming include:

Increased crop yields: By optimizing growing conditions and detecting issues early.

Reduced waste: By applying targeted treatments and minimizing excess water and fertilizer.

Improved resource allocation: By optimizing equipment use and reducing fuel consumption.

Vertical Farming

Vertical farming is a method of growing crops in vertically stacked layers, often in indoor

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environments. This approach offers several benefits, including:

Increased yield per acre: By growing crops in multiple layers, vertical farming can increase yields while reducing land use.

Water conservation: Vertical farming often uses hydroponics or aeroponics, which can reduce water consumption.

Year-round production: Indoor vertical farms can produce crops year-round, regardless of weather conditions.

Reduced transportation costs: By growing crops in urban areas, vertical farming can reduce transportation costs and increase freshness.

Hydroponics

Hydroponics is a method of growing plants in nutrient-rich solutions rather than soil. This approach offers several benefits, including:

Water conservation: Hydroponics can reduce water consumption by up to 90%.

Increased crop yields: Hydroponics can increase crop yields by providing optimal nutrient levels.

Improved crop quality: Hydroponics can improve crop quality by reducing soil-borne diseases and pests.

Year-round production: Hydroponics can be used to grow crops year-round, regardless of weather conditions.

IoT-Enabled Monitoring Systems

IoT-enabled monitoring systems use sensors and other devices to monitor temperature, humidity, light, and soil conditions in real-time. This approach offers several benefits, including:

Real-time monitoring: Farmers can monitor conditions in real-time, allowing for quick response to changes.

Data analysis: IoT-enabled systems can analyze data to detect trends and patterns.

Automated decision-making: IoT-enabled systems can automate decision-making, such as adjusting irrigation systems or climate control.

Improved crop yields: By optimizing growing conditions, IoT-enabled systems can improve crop yields.

Artificial Intelligence (AI) and Machine Learning (ML)

AI and ML can be used in horticulture to analyze data and make predictions about crop yields, disease detection, and optimal growing conditions. This approach offers several benefits, including:

Predictive analytics: AI and ML can analyze data to predict crop yields, detect diseases, and optimize growing conditions.

Automated decision-making: AI and ML can automate decision-making, such as adjusting irrigation systems or climate control.

Improved crop yields: By optimizing growing conditions, AI and ML can improve crop yields.

Reduced waste: By detecting issues early, AI and ML can reduce waste and minimize losses.

By adopting smart horticulture practices, farmers and growers can improve efficiency, productivity and sustainability, ultimately contrib-uting to global food security and environmental stewardship.

Dragon Fruit: Wondrous Fruit of the 21st Century

Kavya Dilleppa Valmiki, Sridhar R., Shivakumar B. S. and A. Pavithra

Introduction

Dragon fruit native to central America and mexico, dragon fruit has a sweet and rich pulp with seeds it has a crunchy texture, like a blend of kiwi fruits and pears, a recently introduced as super fruit in India. It is considered promising remunerative and relatively durable fruit crop. Fruit has very attractive color and mellow mouth melting pulp with black color edible seed embedded in the pulp along with tremendous nutritive property which attracts the growers from different part of India to cultivate this fruit crop which is originated in Mexico and central and South America. It is a long day plant with beautiful night blooming flower that is nicknamed as “Noble woman” or “Queen of the night”. The “Strawberry pear”, “Dragon fruit”, Pithaya, “Night blooming cereus

Nutritional benefits

Nutrient	Amount (per 100 g)	Daily value (%)
Water	87 g	-
Protein	1.1 g	2.1
Fat	0.4 g	-
Carbohydrate	11.0 g	3.4
Fiber	3 g	12
Vitamin B_1 (thiamine)	0.04 mg	2.7
Vitamin B_2 (riboflavin)	0.05 mg	2.9
Vitamin B_3 (niacin)	0.16 mg	0

Health benefits: Dragon fruit has an extremely low amount of cholesterol, which ultimately reduces the chance of heart attack and other diseases caused by accumulation of cholesterol. It’s the perfect fruit to maintain weight. It contains protein as well as omega-3 and omega-6 fatty acids that can help prevent cardiovascular diseases. It is an excellent source of monounsaturated fats, helping the heart stay in great condition. It helps to clean up digestive system. It has high fiber content, which can assist with poor digestion and constipation. Eating the flesh and seeds, which contain good protein, will keep body fortified.

Dragon fruit types/ varities

In dragon fruit there are four main types based on its skin and flesh colour.

***Hylocereus undatus*:** Also known as Pitahaya, Variety has a white flesh with pink skin and green scale. Edible black seeds Shown in Fig 1.

***Hylocereus costaricensis*:** Violet red flesh and pink skin, It’s also known as Costa Rican Pitaya, It's native to Costa Rica, The fruit is magenta and the seeds are pear shaped.

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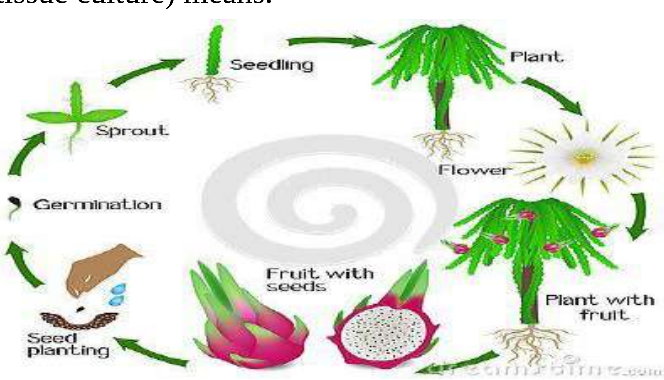
***Hylocereus megalanthus*:** Native to South America, White flesh with yellow skin.

***Hylocereus polyrhizus*:** Also known as Red Pitaya, Variety has a red flesh with its pink skin, Native to Mexico. Most popular type now grown in many countries.

Climatic requirements: It is very ideal to be grown in most parts of the india except the area less rainfall. This reported rainfall reqirement of dragon fruit is 1145- 2540 mm year^{-1}. Dragon fruit plant prefers a dry tropical climate with an average temprature of 20- 29^{0}C, but can withstandtemperatures of 38- 40^{0}C and as low as 0^{0}C for short periods.

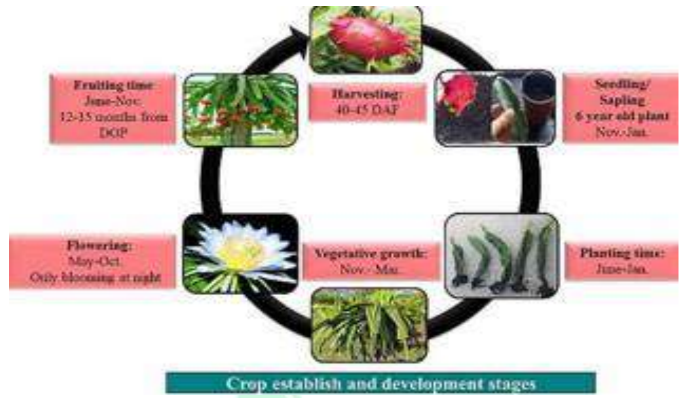
Soil requirement: Dragon fruit could be grown in a wide range of soils, but the soil should be well drained as water logging for long period hampers its growth and favours rotting of stems. The sandy loam soil, rich in organic matter is good for its commercial cultivation. The soil pH of 5.5-6.5 is optimum.

Propagation: The dragon fruit can be propagated by sexual (by seed) as well as asexual (by cuttings and tissue culture) means.



Planting

Rainy season with the onset of monsoon (June to August), is the best time for planting but it can be planted in other seasons too with the provision of irrigation.



Training and Pruning

To maintain proper growth, shape and to maintain proper health of plant require a training and pruning.

Pruning stages and methods

Stage 1: Immediately after harvest during May- June

Stage 2: Prune lateral stems which are grown on main stem and remove overlapped branches

Stage 3: Prune old branches by giving good shape to the plants

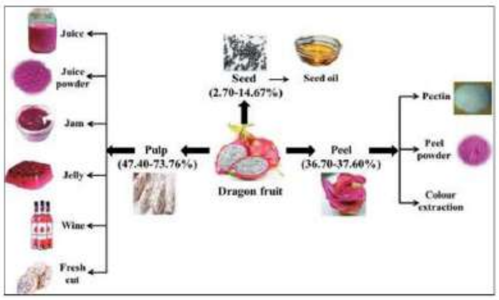
Stage 4: Maintain proper height by removing branches and keep only 2 sub branches for one main stem.

Harvesting

The plants start yielding after 12- 15 months from the date of planting and the fruit maturity can be optimized with the change of fruit pericarp color from green to red. Proper time of harvesting is found after seven days of colour transition. The plants yield the fruits in months between April to October and harvesting can be done three to four times in a month.

Processing and value addition

Dragon fruit pulp and juice with a solution containing 1.5 percent pectin, 55% sugar and 0.9 percent citric acid solution improved the colour as well as other organoleptic characteristics of dragon fruit jam and jelly. In the case of dragon fruit RTS beverage 14 percent pulp, 12 percent sugar and 0.9% were found to be most suitable.



References

Karunakaran, G. and Arivalagan, M. (2019). Dragon Fruit-A new introduction crop with promising market. *Indian Horticulture*, 63(1): 8-11.

Kishore, K. (2016). Phenological growth stages of dragon fruit (*Hylocereus undatus*) according to the extended BBCH-scale. *Scientia Horticulturae*, 213: 294-302.

Sharma, R. K. (2016). Studies of dragon fruit (*Hylocereus* spp.) and its utilization in value added products. M.Sc., Thesis submitted to Vastanrao Naik Marathwada Krishi Vidhyapith, Maharashtra; c2016.

Sonawane, M. S. (2017). Nutritive and medicinal value of dragon fruit. *Asian Journal of Horticulture*, 12(2): 267-271.

Kakade, V., Jinger, D., Dayal, V., Chavan, S., Nangare, D. D., Wakchaure, G. C. and Dinesh, D. (2020). Dragon Fruit: Wholesome and remunerative fruit crop for India. *Food and Scientific Reports*, 1(12): 44-48.

Smart Post-Harvest Practices for Profitable Fruit Farming

Shivali Sharma, Raman Choudhary, Gaurav Sharma, Priyanka Sharma and Ghan Shyam Abrol

Introduction

Post-harvest management in fruits is an essential discipline that focuses on preserving quality, reducing losses and maximizing profitability for farmers. It encompasses all activities that take place between harvest and consumption, grading, cleaning, packaging, storage, transportation, processing and value addition, each playing a crucial role in curbing post-harvest losses and enhancing farmers' income. According to the Indian Council of Agricultural Research (ICAR) and the National Centre for Cold Chain Development (NCCD), India loses nearly 25-40% of its total fruit production annually due to inadequate post-harvest management, poor handling, and lack of cold-chain facilities. Minimizing these losses could substantially raise farmers' income without increasing cultivated area, making it one of the most sustainable pathways to agricultural prosperity.

Grading: Enhancing Market Value

Grading is the first step toward market readiness and export quality assurance. It involves sorting fruits based on physical attributes such as size, shape, color, and weight, ensuring uniformity, appearance, and consistency, critical factors influencing consumer preference and pricing. Well-graded fruits command 30-50% higher prices than ungraded produce in both domestic and international markets (APEDA, 2023). For instance, export-quality Alphonso mangoes, Kinnow mandarins, and apples are carefully graded according to Agmark and Codex standards to meet quality norms abroad. Modern technologies are revolutionizing grading efficiency, AI-based optical sensors, machine vision systems, and laser scanners can rapidly detect defects, measure color intensity, and sort fruits with precision far exceeding manual grading. Such systems minimize human error, save labour, and enable large-scale, consistent quality control. Moreover, grading helps reduce handling and microbial losses by separating immature, diseased, or damaged fruits early in the chain, thereby extending shelf life and improving overall marketable yield.

Cold Storage: Extending Shelf Life and Market Reach

Temperature management is the basis of post-harvest quality. Cold storage slows down respiration, ripening, and microbial decay, thus preserving texture, flavour, and nutritional value. Fruits like apples, grapes, citrus, and mangoes can be stored under controlled temperature (0-13 °C, depending on the crop) and humidity (85-95%) to retain freshness for weeks or months. Controlled Atmosphere (CA) and Modified Atmosphere (MA) storage further enhance longevity by balancing

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oxygen, carbon dioxide, and nitrogen concentrations inside storage chambers. This scientific approach not only maintains quality but also provides farmers the strategic advantage of timing sales, they can hold produce until off-season periods when prices rise, ensuring better profitability. According to FAO and NCCD reports (2023), efficient cold chain systems can reduce post-harvest losses by 20-30%, while enabling access to distant metropolitan and export markets. Additionally, the growth of integrated cold chain logistics, combining pre-cooling units, packhouses, reefer vans, and retail cold displays, has improved the reach of perishable fruits, bridging the gap between farm and consumer. Government initiatives such as PM-Kisan Sampada Yojana, MIDH, and Operation Greens are actively promoting cold storage infrastructure and refrigerated transportation networks.

Value Addition: Converting Losses into Profits

Value addition transforms perishable fruits into durable, marketable, and often premium products like jams, juices, jellies, candies, pulp, pickles, dried fruits, and concentrates. This not only enhances shelf life and consumer convenience but also creates employment opportunities and rural entrepreneurship.

For example:

- ✓ Surplus or blemished mangoes can be processed into pulp or nectar, earning farmers up to three times more income than selling raw fruit.
- ✓ Guava, aonla, and papaya can be turned into jams, beverages, or dehydrated slices, while ber and custard apple lend themselves well to preserves and frozen pulp.
- ✓ FSSAI-compliant small-scale units ensure product safety and market acceptance.

Processing thus converts seasonal gluts into profitable opportunities, ensuring income stability even during periods of oversupply. Moreover, by promoting women-led microenterprises and farmer producer organizations (FPOs), value addition strengthens local economies and food security.

Environmentally, fruit processing also supports sustainability residues like peels, seeds, and pulp waste can be utilized for bio-fertilizer production, animal feed, or pectin extraction, reducing waste and closing nutrient loops.

Fruit Processing: A Pathway to Sustainable Agribusiness

Fruit processing bridges the gap between farm and consumer by adding resilience and stability to the fruit value chain. From cottage industries producing homemade jams and pickles to industrial-scale units manufacturing frozen pulp, concentrates, and canned products, this sector plays a transformative role in India’s horticultural economy. According to the Ministry of Food Processing Industries (MoFPI, 2024), expanding fruit processing capacity by just 10% could generate millions of jobs and reduce fruit wastage by over 15%. Furthermore, the export of processed fruit products contributes significantly to foreign exchange earnings, especially in markets like the Middle East, Europe and Southeast Asia. With increasing consumer demand for ready-to-eat, health-oriented products, value-added fruit items such as cold-pressed juices, fruit bars, natural sweeteners, and probiotic beverages are emerging as lucrative opportunities for agripreneurs.

Economic and Environmental Impacts

Effective post-harvest management is both an economic imperative and an environmental necessity. Each kilogram of fruit lost represents wasted inputs water, fertilizers, energy, and labour, used during production. By reducing post-harvest losses, farmers not only save these resources but also increase their profit margins without expanding cultivation.

Economically, post-harvest management:

- ✓ Provides pricing flexibility, allowing farmers to store and sell at favorable times.
- ✓ Reduces dependence on middlemen by facilitating direct marketing and aggregation through FPOs.
- ✓ Encourages income diversification via processed product lines.

Environmentally, better handling and storage cut greenhouse gas emissions from decomposing waste and lower resource intensity per unit of food consumed.

Government Support and Future Prospects

Recognizing the importance of post-harvest management, the Government of India has integrated it into multiple schemes such as:

- ✓ Mission for Integrated Development of Horticulture (MIDH) -for packhouses, cold storages and ripening chambers.
- ✓ Pradhan Mantri Kisan Sampada Yojana (PMKSY) - promoting agro-processing clusters and Mega Food Parks.
- ✓ Operation Greens (TOP to TOTAL) - stabilizing prices and supporting cold chain infrastructure.
- ✓ National Horticulture Board (NHB) - providing credit-linked subsidies for post-harvest infrastructure.

In addition, ICAR-CIPHET (Ludhiana) and CFTRI (Mysuru) have developed affordable technologies for fruit preservation, dehydration, and packaging, easily adaptable by farmer groups and rural entrepreneurs.

Conclusion

Integrating scientific grading, cold storage, and value-added processing can transform fruit cultivation from a subsistence occupation into a profitable, sustainable, and resilient agribusiness. Reducing post-harvest losses is not just about saving produce, it’s about empowering farmers, ensuring food security, and protecting the environment. Government-supported infrastructure, FPO-based processing clusters, and farmer training in post-harvest technologies will be crucial in achieving this transformation. As the saying goes, “The real profit in fruits begins after harvest” and efficient post-harvest management ensures that every fruit harvested truly counts.

References

FAO (2023). Reducing Food Loss and Waste in Fruits and Vegetables Supply Chains.

NCCD (2023). Post-Harvest Loss Assessment of Major Fruits in India.

ICAR-CIPHET (2022). Post-Harvest Management and Value Addition in Horticultural Crops.

APEDA (2023). Agmark and Export Quality Standards for Fruits and Vegetables.

MoFPI (2024). Annual Report on Food Processing Sector in India.

FSSAI (2024). Food Safety and Standards for Fruit Products.

Veld Grape: A Forgotten Herb with Modern Promise

Anamika, Shweta and Kulwant Singh

Abstract

Veld grape (*Cissus quadrangularis*) is a fast-growing, drought-tolerant climbing plant widely valued for its medicinal, nutritional and environmental uses. Traditionally, it has been used to heal bone fractures, relieve joint pain, improve digestion and support menstrual health. Rich in calcium, vitamin C and antioxidants, it also supports weight management and overall wellness. The plant's bioactive compounds are beneficial in food, cosmetics and pharmaceuticals. Due to its resilience and ecological benefits, veld grape holds great promise for sustainable agriculture and natural healthcare advancement.

Introduction

Veld grape, scientifically called *Cissus quadrangularis*, is a strong climbing plant that belongs to the Vitaceae family. It is well-known for its thick, fleshy stems that have a unique square shape. This plant naturally grown in warm regions of Asia, Africa and the Arabian Peninsula. It is very hardy and can live in dry places where water is limited and soils are poor. This makes it an important plant for gardens and farming in areas with tough climates. The leaves of veld grape are usually simple or have a few lobes and they grow at joints of the stems. The plant produces small flowers that are greenish, white or yellow. After flowering, these turn into round barriers that become red or purple when ripe. The plant can grow quickly and reach several meters in length, often climbing on other plants or structures. Veld grape has been used for many years in traditional medicines, especially in India, Africa and Thailand. People use its stems, roots and leaves to help heal broken bones faster, reduce joint pain and support digestion. Studies have shown that this plant contains important nutrients like vitamins C and antioxidants, as well as special compounds that help reduce swelling and heal the body. Because of these features, it is popular for bone health and inflammation relief. Besides its use in medicine, veld grape is also edible. In some cultures, young shoots and leaves are cooked as vegetables and the fruit is eaten fresh. The ash from the plant is sometimes used as a substitute for baking powder. It is easy to grow by cutting parts of stem and planting them, making it a convenient plant for home gardeners and sustainable farming.

Botanical Description

- ✓ It is a herbaceous, deciduous shrub or climbing

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plant that usually grows up to 1.5 meters in height.

- ✓ The stems are green and slow clear nodes. They produce simple, slender tendrils that help the plant climb or trail on nearby structure (Figure 1).
- ✓ Leaves are simple, fleshy and green, shaped from oval to heart-like (ovate to cordate) with toothed or serrated edges (Figure 1).
- ✓ The plant bears small greenish-white flowers, which appear in cluster or cymes. When matured, the flower turn into small round berries, which become black or red upon ripening (Figure 2).
- ✓ The root system is tuberous and fleshy, allowing the plant to store water and nutrients, which help it survive in dry conditions.
- ✓ Common names include Devil's Backbone, Adamant creeper, Pirandai, Veld Grape, Hadjod and Asthisamharaka across different regions of India and Africa (Srivastva *et al*., 2011; Joseph *et al*., 2013).

Fig. 1: Leaves and stem

Fig. 2: Flower

Uses and Benefits

Medicinal uses (traditional and modern)

Bone health: It has been used traditionally to support bone healing and treat osteoporosis due to its calcium content and ability to promote bone growth (Srivastava *et al*., 2011; Joseph *et al*., 2013; Brahmkshatriya *et al*., 2015).

Joint health: It improves joint health, reducing inflammation and joint pain, which might be significant for illnesses such as arthritis (Brahmkshatriya *et al*., 2015; Siddiqua and Mittapally, 2017).

Gastrointestinal disorders: It treats digestive disorders like diarrhea and gastritis due to its anti-inflammatory and gastro protective effects (Siddiqua and Mittapally, 2017).

Menstrual relief: It helps to balance hormones and reduce inflammation, it has been used to treat menstrual cramps, bloating and pain (Srivastava *et al*., 2011)

Nutritional uses

- ✓ Veld grape is rich in essential nutrients including vitamin C, calcium, antioxidants and bioactive compounds.
- ✓ It aids digestion, reduces inflammation and promotes gastrointestinal health
- ✓ It helps in weight management by enhancing lipid metabolism and reducing fat absorption, while providing antioxidant and anti-inflammatory benefits **(**Oben *et al*., 2006; Stohs and Ray, 2013).

Industrial uses

- ✓ It is used as a natural ingredient in functional foods, health drinks, protein shakes and herbal beverages for its antioxidant and wellness benefits (Murthy *et al*., 2003).
- ✓ The bioactive compounds of veld grape are

utilized in cosmetic products aimed at skin repair, anti-aging and wound healing (Jain *et al*., 2015; Sundaran *et al*., 2020; Dhanasekaran, 2020).

Ornamental and Environmental uses

- ✓ *Cissus quadrangularis* is grown as an ornamental climber for its attractive, lush green foliage and fast growth, ideal for covering trellises, fences and walls.
- ✓ It is used in landscaping to create green shade and enhances garden aesthetics due to its dense and decorative vine structure.
- ✓ The plant helps prevent soil erosion by stabilizing sandy and degraded soil with its extensive root system.
- ✓ Their dense growths can supress invasive weeds, contributing to ecological balance and environmental sustainability.

Future scope

Veld grape looks very promising because of its important health and environmental benefits. It can be grown more widely with better farming methods, especially by using stem cuttings to produce true-to-type plants. On-going research on its genetics will help identify stronger varieties with more active compounds, which can improve its use in medicines. The plant is also good for dry area because it can survive droughts, which supports sustainable farming in tough conditions. Additionally new studies on its health effects may lead to the development of better treatments for bone problems, inflammation and metabolic diseases. Overall, veld grape has great potential in health care, agriculture and environmental management.

Conclusion

Veld grape is a remarkable plant that offers many health and environmental benefits. It has been used traditionally to help heal bones, reduce inflammation and improve digestion. Besides its medicinal value, it is also important in industries like food and cosmetics because of its natural qualities. It has great potential to become an important natural plant for health, wellness and sustainable farming through on-going research and better cultivation.

References

Brahmkshatriya, H. R., Shah, K. A., Ananthkumar, G. B. and Brahmkshatriya, M. H. (2015). Clinical evaluation of *Cissus quadrangularis* as osteogenic agent in maxillofacial fracture: A pilot study. *AYU (An International Quarterly Journal of Research in Ayurveda),* 36(2): 169-173.

Dhanasekaran, S. (2020). Phytochemical characteristics of aerial part of *Cissus quadrangularis* (L) and its in-vitro inhibitory activity against leukemic cells and antioxidant properties. *Saudi Journal of Biological Sciences,* 27(5):, 1302-1309.

Srivastava, K. A., Srivastava, P., Tiwari, B. N., Mishra, J. N., Behera, B. R. and Shrivastava, A. K. (2011). A plant (*Cissus quadrangularis*) with various ethnopharmacological actions: A review. *Journal of Pharmacy Research,* 4(6): 1887-1890.

Jain, S. and Kohli, S. (2015). Isolation and evaluation of chemical constituents of *Cissus quadrangularis*. *Natural Products Chemistry & Research*, 3(6): 1-3.

Joseph, B., George, J. and Mohan, J. (2013). *Cissus quadrangularis* in the treatment of osteoporosis. *World Journal of Pharmaceutical Research*, 2(3): 596-605.

Murthy, K. C., Vanitha, A., Swamy, M. M. and Ravishankar, G. A. (2003). Antioxidant and antimicrobial activity of *Cissus quadrangularis* L. *Journal of Medicinal Food*, 6(2): 99-105.

Oben, J., Kuate, D., Agbor, G., Momo, C. and Talla, X. (2006). The use of a *Cissus quadrangularis* formulation in the management of weight loss and metabolic syndrome. *Lipids in Health and Disease*, 5(1): 1-7.

Siddiqua, A. and Mittapally, S. (2017). A review on *Cissus quadrangularis*. *The Pharma Innovation Journal*, 6(7, Part E): 329-333.

Stohs, S. J. and Ray, S. D. (2013). A review and evaluation of the efficacy and safety of *Cissus quadrangularis* extracts. *Phytotherapy Research*, 27(8): 1107-1114.

Sundaran, J., Vasanthi, M., Kamalapathy, M., Bupesh, G. and Sahoo, U. (2020). A short review on pharmacological activity of *Cissus quadrangularis*. *Bioinformation*, 16(8): 579-583.

Agronomical Measures for Managing Natural Resources in Dry Lands

A. P. Singh, Monika Banotra, Brinder Singh, Sunny Raina and Chamanpreet Kour

Natural resource management (NRM) aims for the efficient and sustainable utilization of renewable and non-renewable natural resources. In other words, NRM in agriculture referred to human administration and sustainable utilization of biophysical resources for the production of food, feed, fiber and fuel. Agriculture is the single largest livelihood sources in India with nearly two thirds of people depend on it. Growing of crops entirely under rainfed conditions is known as dryland agriculture.

Depending on the amount of rainfall received, dryland agriculture can be grouped into three categories:

Dry farming: Cultivation of crops in regions with annual rainfall less than 750 mm. These are arid regions with a growing season (period of adequate soil moisture) less than 75 days.

Dryland farming: Cultivation of crops in regions with annual rainfall more than 750 mm. These are semi arid tracts with a growing period between 75 and 120 days.

Rainfed farming: Cultivation of crops in regions with annual rainfall more than 1150 mm. These are humid regions with growing period more than 120 days.

Importance of Dry farming in Indian Agriculture

- ✓ About 70% of rural population lives in dry farming areas and their livelihood depend on success or failure of the crops.
- ✓ Dryland Agriculture plays a distinct role in Indian Agriculture occupying 60% of cultivated area and supports 40% of human population and 60 % livestock population.
- ✓ The contribution (production) of rainfed agriculture in India is about 42 % of the total food grain, 75 % of oilseeds, 90 % of pulses and about 70 % of cotton.
- ✓ More than 90 per cent of the area under sorghum, groundnut, and pulses, 82 to 85 per cent area under maize and chickpea, 78 percent area under cotton, 65.8 per cent area under rapeseed/ mustard is rainfed. Interestingly, but not surprisingly, 61.7, 44.0, and 35.0 per cent area under rice, barley and wheat, respectively, is rainfed.
- ✓ The productivity of grains already showed a plateau in irrigated agriculture due to problems related to nutrient exhaustion, salinity build up and raising water table. Therefore, the challenges of the present millennium would be to produce more from dry lands while ensuring conservation of existing resources.
- ✓ Dry lands offer good scope for development of agro forestry, social forestry, horti-silvi-pasture and such other similar systems which will not only supply food, fuel to the village people and

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fodder to the cattle but forms a suitable vegetative cover for ecological maintenance.

Hence, new strategies would have to be evolved which would make the fragile dryland ecosystems more productive as well as sustainable.

Area under Dry Lands

In India out of the total cultivated area of 143 million hectare, the area under dry lands is about 85 million hectare, which comes to 60%.

Dry land area in different regions of India

Region	States	Per cent of rainfed area
Cold and northern region	Jammu and Kashmir, Uttaranchal and Himachal Pradesh,	60 to 81
Arid western Region	Rajasthan and Gujarat	66 to 88
Semi arid to arid central and southern region	Madhya Pradesh, Maharashtra, Andhra Pradesh, Karnataka, Tamil nadu	76 to 82
Sub humid to humid eastern region	Eastern Uttar Pradesh, Bihar, Jharkhand, Orissa, West Bengal	33 to 73
Humid to per humid north eastern region	Assam and north eastern hill states	Up to 90

Characteristics of Dry Land Areas

- ✓ Uncertain, ill-.distributed and limited annual rainfall.
- ✓ Occurrence of extensive climatic hazards like drought, flood etc.
- ✓ Undulating soil surface.
- ✓ Occurrence of extensive and large holdings.
- ✓ Practice of extensive agriculture i.e. prevalence of monocropping etc;
- ✓ Relatively large size of fields.
- ✓ Similarity in types of crops raised by almost all the farmers of a particular region.
- ✓ Very low crop yield.
- ✓ Poor market facility for the produce.
- ✓ Poor economy of the farmers.
- ✓ Poor health of cattle as well as farmers.

Constraints for Crop Production in Dryland Areas

The low productivity of agriculture in dry farming regions is due to the cumulative effect of many constraints for crop production. The constraints can be broadly grouped into:

Climatic constraints.	Heavy weed problem.
Soil related constraints.	Lack of suitable varieties.
Traditional cultivation practices.	Socio economic constraints

Climatic constraints

- ✓ Rainfall characteristics
- ✓ Variable rainfall(coefficient of variation)
- ✓ Intensity and distribution Aberrations or variations in monsoon behavior
- ✓ Late onset of monsoon
- ✓ Early withdrawal of monsoon
- ✓ Prolonged dry spells
- ✓ High atmospheric temperature
- ✓ Low relative humidity
- ✓ Hot dry winds
- ✓ High atmospheric water demand

Soil Constraints

- ✓ Inadequate soil moisture availability
- ✓ Poor organic matter content
- ✓ Poor soil fertility
- ✓ Soil deterioration due to erosion (wind, water)
- ✓ Soil crust problem
- ✓ Presence of hard layers and deep crack

Traditional cultivation practices

- ✓ Ploughing along the slope

- ✓ Broadcasting seeds/ sowing behind the country plough leading to poor as well as uneven plant stand
- ✓ Monsoon sowing
- ✓ Choice of crops based on rainfall
- ✓ Application FYM in limited quantity
- ✓ Hand weeding
- ✓ Mixed cropping
- ✓ Use of conventional system of harvesting
- ✓ Traditional storage system

Heavy Weed Infestation: This is the most serious problem in dryland areas. Unfortunately the environment congenial for crop growth is also congenial for weed growth. Weed seeds germinate earlier than crop seeds and try to suppress the crop growth. The weed problem is high in rainfed areas because of continuous rains and acute shortage of labor. The weed suppression in the early stage of crop growth is required to reduce the decrease in crop yields.

Lack of Suitable Varieties: Most of the crop varieties available for cultivation in dry lands are meant for irrigated agriculture. There are no any special varieties exclusively meant for dryland areas. Hence still more efforts are required to develop varieties in different crops exclusively meant for dryland agriculture.

Socio-economic Constraints

The economic condition of the dryland farmers is very poor because:

- ✓ Less access to inputs
- ✓ Non availability of credit in time
- ✓ The risk bearing capacity of dryland farmer is very low

Hence the dryland farmers resort to low input agriculture which results in poor yields.

Management of Natural Resources

The natural resources that are to be managed on sustainable basis are soil, water, vegetation and climate. India is blessed with vast natural resources of land, water, vegetation and climate but with poor quality of life.

Characterization and development of sustainable land use plans for each agro ecological region in the country.

- ✓ Soil and moisture conservation.
- ✓ Integrated soil fertility management
- ✓ Inter basin transfer of surface flow which is otherwise going as waste for seas and oceans.
- ✓ Creation of live storage of water by constructing reservoirs.
- ✓ Integrated water management of surface and ground water sources
- ✓ On farm irrigation water management to enhance water use efficiency

Modern concepts of Tillage

Minimum tillage: It is the tillage system aimed at reducing the number of tillage operations to the minimum level i.e. necessary for better seed bed preparation, rapid germination for maintenance of optimum plant stand. The advantages are:

- ✓ Reduction of soil erosion
- ✓ Reduction of soil compaction
- ✓ Increases infiltration of water

- ✓ Increased soil fertility due to decomposition of crop residues
- ✓ Less cost of production because less number of tillage operations

Modern Smart Technologies for Resource Management

Soil management: Tillage and Soil fertility (Site specific nutrient management)

Sowing and Seedling management

Water management

Soil management

Tillage: It may be described as the practice of modifying the state of the soil in order to provide conditions favorable to crop growth.

The objectives of tillage in dry lands are

- ✓ Develop desired soil structure for a seed bed which allows rapid infiltration and good retention of rainfall.
- ✓ Minimize soil erosion by following practices such as contour tillage, tillage across the slope etc.
- ✓ Control weeds and remove unwanted crop plants.
- ✓ Manage crop residues
- ✓ Obtain specific land configurations for in- situ moisture conservation, drainage, planting etc.
- ✓ Incorporate and mix manures, fertilizers, pesticides or soil amendments into the soil.
- ✓ Accomplish segregation by moving soil from one layer to another, removal of rocks or root harvesting.

Zero tillage or no-till system: It is an extreme form of minimum tillage where primary tillage is completely avoided and secondary tillage is restricted to crop zone. In this method use of machinery should have attachments for four operations namely, cleaning the narrow strip over crop row, open the soil for seed insertion, placing the seed and covering the seed. The Advantages are:

- ✓ Increases the biological activity in the soil
- ✓ Organic matter content of the soil is increase due to decomposition of crop residues
- ✓ Reduction of surface runoff.

Conservation/mulch tillage: The objectives are to achieve soil and water conservation and energy conservation through reduced tillage operations. Both systems usually leave crop residue on the surface and each operation is planned to maintain continuous soil coverage by residue or growing plants.

Soil Fertility (Site Specific Nutrient Management)

Site specific nutrient management is an approach to feed crops with nutrients as and when needed. The application and management of nutrients are dynamically adjust to crop needs of location and seasons.

Sowing and Seedling management: Poor or suboptimal population is a major reason for low yields in rainfed crops. Establishment of an optimum population depends on:

Seed treatment	Depth of sowing
Seed hardening	Method of sowing
Time of sowing	Crop geometry
Sowing at optimum soil moisture	

Water Management

Mulches: Mulch is any covering material applied on the soil surface to reduce evaporation losses. This material may be grown and maintained in place, or any material grown and modified before placement or any material processed or manufactured and transported before placement.

Types of mulches

- ✓ Soil mulch or dust mulch
- ✓ Straw and stubble mulch
- ✓ Plastic mulches
- ✓ Chemical mulches

Water productivity: The Water Productivity term plays a crucial role in modern agriculture which aims to increase yield production per unit of water used, both under rainfed and irrigated conditions. Modern irrigation practices adopted for enhancing water productivity dryland areas are as follows:

Deficit irrigation	Supplemental irrigation
Drip irrigation	Alternate Furrow Irrigation (AFI)
Sprinkler irrigation	Others Methods

Deficit irrigation: Deficit irrigation is an optimization strategy in which irrigation is applied during drought-sensitive growth stages of a crop. DI maximizes water productivity, which is the main limiting factor in dry areas, DI aims to stabilizing yields and to obtaining maximum WP rather than maximum yields.

Advantages of deficit irrigation

- ✓ Maximizes water productivity.
- ✓ It is economically more profitable for the farmer than maximizing yield.
- ✓ Decreases the risk of insect's pests and other diseases attack.
- ✓ Reduces nutrient loss through leaching and thus lower fertilizer needs on the field.

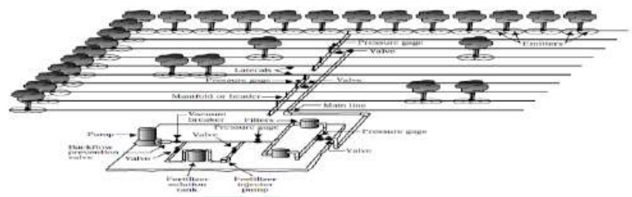

Fig.: Drip Irrigation

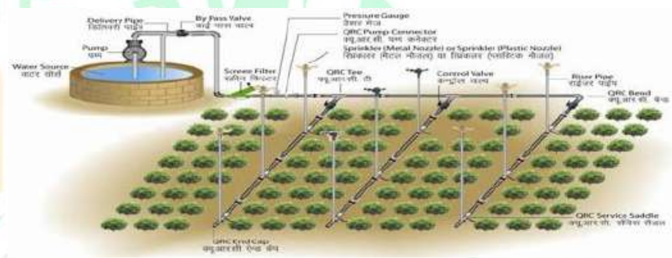

Fig.: Sprinkler irrigation

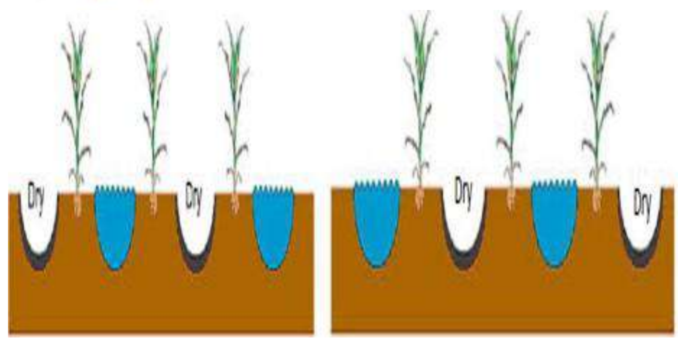

Fig: Alternate Furrow Irrigation

Water Harvesting: Rainwater harvesting is the simple process or technology used to conserve Rainwater by collecting, storing, conveying and purifying of Rainwater that runs off from rooftops, parks, roads, open grounds, etc. for later use.

Climate Variability and Adaptation Strategies for Rainfed Agriculture in India

Monika Banotra, A. P. Singh, Rohit Sharma, Jai Kumar and Chamanpreet Kour

Indian economy is mainly dependent on agriculture, which contributes 21 per cent of the country's GDP and 60 per cent of the employment. Rainfed agriculture occupies 67 percent net sown area, contributing 44 percent of food grains and supporting 40 percent of the population. In view of the growing demand for food grains in the country, there is a need to increase the productivity of rainfed areas from the current 1 t ha^{-1} to 2 t ha^{-1} in the next two decades. The quality of natural resources in the rainfed ecosystem is gradually declining due to over exploitation. Rainfed areas suffer from bio-physical and socio economic constraints affecting the productivity of crops and livestock. These include soil and rainwater conservation measures, efficient crops and cropping systems matching to the growing season. The farming systems approach in rainfed agriculture not only helps in addressing income and employment problems but also ensures food security.

Climate change is a severe threat that can lead to increasing damage to the ecological foundations of agriculture such as, land, water, forests, biodiversity and the atmosphere. There are distinct possibilities for occurrence of adverse changes in climate threatening the future food security across the nations including India. During the 20th century, there had been a significant increase in the concentration of greenhouse gases (GHG) in the atmosphere contributing nearly 64% of the global warming (379 ppm of CO_2). Experts fear that if the emissions of the GHG continue to increase, then it will cause adverse effects on environment and food security of human beings. The Inter-Government Panel on Climate Change (IPCC, 2007) has projected a possible increase in temperature between 1.5 ^{0}C and 5.8 ^{0}C with the best possible value of 3.8^{0}C by 2100 AD. The net result of climate change as anticipated is recurring drought and floods and significant changes in production environments.

Climate change adaptation for rainfed agriculture includes practices like implementing soil and water conservation, switching to resilient crop varieties and cropping systems suited to variable growing seasons, and diversifying livelihoods to buffer against climate shocks. Other key strategies involve improving access to accurate climate information and forecasts, using water harvesting techniques, adopting conservation agriculture practices and leveraging indigenous knowledge to manage risks and enhance farm resilience. The different Climate change adaptation strategies for Rainfed Agriculture are described as under:

Different Climate change adaptation strategies for Rainfed Agriculture

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Crop and Sowing Adjustments

Change cropping patterns: Select crops that are more tolerant to drought or fit the changing growing season.

Adjust sowing dates: Advance or delay planting to avoid periods of expected water stress based on local weather patterns and forecasts.

Promote crop diversification: Introduce a variety of crops to reduce reliance on a single one and manage risk.

Use resilient crop varieties: Cultivate varieties that can better withstand drought and temperature fluctuations.

Soil and Water Management

Implement water conservation techniques: This includes techniques like deep plowing and applying manure to improve soil moisture retention.

Practice conservation agriculture: Use practices that maintain soil structure and organic matter, like no-till farming.

Utilize soil and rainwater harvesting: Collect and store water for use during dry spells.

Apply organic matter: Incorporate manure and other organic materials to enhance soil health and water holding capacity.

Livelihood Diversification

Explore off-farm income: Engage in other activities like renting out land or other non-agricultural jobs to supplement farm income and reduce vulnerability.

Integrate livestock: Incorporate livestock into the farming system to provide an additional source of income and food security.

System-Level and Supportive Strategies

Access to Information

Utilize climate information services: Get more accurate and localized weather forecasts to make informed decisions about farming.

Leverage extension services: Get support and education on new farming practices and technologies from extension workers.

Market and Financial Tools

Access credit and insurance: Financial instruments like credit and farm insurance can help farmers cope with and recover from climate shocks.

Indigenous Knowledge

Apply traditional knowledge: Integrate time-tested local knowledge with modern scientific approaches to find locally appropriate solutions.

Climate change and its variability are emerging as major challenges facing Indian agriculture. The high inter and intra-seasonal variability in rainfall distribution, extreme temperature and rainfall events are causing crop damages and huge losses to farmers. Each year, one or the other part in the country is affected by droughts, floods, cyclones, hailstorms, frost and other climatic events.

Hail storms (February- March -2014): Hail storms were hit the states of Maharashtra, Madhya Pradesh, Rajasthan, Haryana, Karnataka and Telangana during February to March 2014. There was lot of damage to field as well as horticultural crops.

Hudhud cyclone (October 2014): Hudhud caused extensive damage to the city of Visakhapatnam and the neighboring districts of Vizianagaram and Srikakulam of Andhra Pradesh.

Damage to Agriculture: kharif/ *rabi*: 182128 hectares: Climate change studies pertaining to India show enough evidence of rising mean temperatures during post-1970 period. It was reported that greater warming (mean annual surface air temperature) of 0.21 °C/10 years during post-1970 period as compared to 0.51 °C/100 years during the past century. On the other hand, all-India average monsoon rainfall is found trend-less over an extended period starting from the year 1871, though significant spatial variations are found at division level. At present in India, blue and green water availability are above the 1300 m^3 $capita^{-1}$ $year^{-1}$ threshold in present. However, with climate change, blue-green water availability is estimated to decrease to below 1300 m^3 $capita^{-1}$ $year^{-1}$, implying that by 2050, all of India could be exposed to water stress. Resilience to climate change will depend on increasing agricultural productivity with available water resources; refining technologies and timely deployment of affordable strategies to accomplish potential levels of arable land and water productivity.

Assessment of Vulnerability to Climate Change

Atlas on vulnerability of Indian agriculture to climate change was prepared under National Innovations on Climate Resilient Agriculture (NICRA) project of Indian Council of Agricultural Research (ICAR) considering a number of aspects including such weather related aspects as incidence of droughts, floods and cyclones, projected changes in rainfall and temperatures in future. The institute developed vulnerability index and based on this index, all the districts were divided into five categories with equal number of districts. It can be observed that districts with higher levels of vulnerability are located in the western and peninsular India. It is also observed that the highly fertile indo-genetic plains are relatively more sensitive, but less vulnerable because of higher adaptive capacity and lower exposure.

Adaptation and Mitigation Measures

The first step is to watch the weather forecast and plan the operations accordingly by following the options available in district agricultural contingency plans.

Weather Forecast and Agro met Advisory

All India Coordinated Research Project on Agro meteorology (AICRPAM) under ICAR issues weekly National Agro met Advisory Services Bulletins in collaboration with India Meteorological Department (IMD) during southwest monsoon season. In addition to this, daily rainfall status of the country during southwest monsoon is monitored by AICRPAM and based on these weekly bulletins, 'Status of monsoon, progress in kharif sowing and agro met advisory for deficit/excess rainfall areas' are prepared and supplied to the stake holders. It is also kept in the website www.cropweather outlook.com

District Agricultural Contingency Plans (DACPs) to Mitigate Climate Change: CRIDA in collaboration with SAUs and ICAR Institutes has prepared 614 district level agricultural contingency plans to meet various natural calamities like drought, floods, cyclones, temperature extremes, etc. These plans not only deal with agriculture but also with allied sectors like horticulture, livestock, fisheries, etc. These contingency plans are available on the CRIDA website (www.crida.in) and also on Department of Agriculture and Cooperation (DAC), Ministry of Agriculture and Farmers Welfare, Government of India.

Production System based Adaptation and Mitigation Measures: The rainfed agro-ecosystem has been sub-divided into 5 homogenous production systems, viz.,

- ✓ Rainfed rice based system
- ✓ Nutritious (coarse) cereals based system
- ✓ Oilseeds based system
- ✓ Pulses based system

Rainfed Rice-based Production System: The system is prevalent in Eastern and Northeastern part of India which is experiencing negative departure in rainfall. Any decrease in rainfall associated with increase in temperature due to climate change, will have an adverse impact on pollen sterility and germination. The effect will be more pronounced in fine quality varieties of rice like basmati. Rice production system is considered to be non-eco-friendly as it is one of the sources of release of methane and nitrous oxide, greenhouse gases responsible for climate change. The climate change mitigation strategy thus should aim at:

- ✓ Adoption of aerobic, direct seeded & SRI method of rice cultivation to minimize the release of harmful gases
- ✓ Growing of legumes as relay crop in rice fallows and intercropping with pigeon pea, wherever feasible
- ✓ Boundary bund plantation of *Gliricidia* and *Pongamia* and use of leaves as green leaf mulch for saving on nitrogenous fertilizers

Nutritious (coarse) Cereal-based Production System: Coarse cereals are staple food of poor people and principal source of fodder for livestock. The area under millets excepting maize is showing a declining trend. Nutritious cereals like sorghum, pearl millet and finger millet despite their low cost of cultivation and having greater yield stability and drought hardiness characteristics are losing area due to poor patronage by people and government alike. This production system needs reinforcement as it is highly adaptable to climate change mainly through government policies like:

- ✓ Higher Minimum Support Price (MSP) for nutritious millets as an incentive to the growers as it supports livestock too. The pressure on forest and grazing land can be minimized by expanding area under millets. This will benefit both the environment as well as livestock1.
- ✓ Inclusion of these millets in public distribution system (PDS) as it can to some extent meet the nutrition deficiency in the poor in rural areas and gradual removal of fine cereals like rice and wheat (having high demand of water) from PDS.

Oilseeds based Production System: Oilseed crops are grown both during *kharif* and *rabi* seasons under sole, inter and sequence cropping systems and are most affected by biotic and biotic stresses. Most oilseeds have shown positive response to climate change particularly elevated CO_2. However, variability in rainfall may result in more number of dry or wet spells affecting their performance. This will be an additional cause of concern and can be overcome mainly through soil moisture conservation, rainwater Harvesting and recycling. The strategy should focus on: Promotion of *in-situ* conservation measures like broad-bed & furrow, conservation furrow, ridge and furrow, etc.

- ✓ Individual and community-owned farm ponds for water harvesting and recycling for supplemental irrigation.
- ✓ Promotion of site-specific nutrient management (SSNM) and thrust on seed village concept as a contingency measure.

Pulses based Production System: Ninety per cent of pulses are grown under rainfed conditions as intercrops or in sequence cropping system all over the country. Pulses have shown a positive response to elevated CO_2. Pigeon pea and chickpea are the two most important pulse crops and grown during *kharif* and *Rabi* seasons, respectively. Pigeon pea because of its longer growing season, generally experiences terminal drought due to withdrawal of monsoon especially if it is an early withdrawal, while chickpea suffers from lack of residual moisture in the soil profile during *Rabi*. Supplemental irrigation to both the crops in general and chickpea in particular can, however, double the crop yield. The drought mitigation erasures thus lie in adopting *in-situ* soil moisture conservation measures like ridge and furrow for pigeon pea and *ex-situ* harvesting of rain water through farm ponds, percolation ponds or check dams. In addition to rainwater conservation and harvesting, promotion of short duration varieties will improve the productivity of these crops and can cope up with changing climatic scenarios.

Risk Transfer Measures: One of the measures to avert the risk of climate change impacts is to opt for insurance and the National Agriculture Insurance Scheme adequately covers all the risks involved of all the farmers including small and medium farmers in terms of insurance cover. The anomalies have been addressed in the new Insurance Policy titled, Pradhan Mantri Fasal Bima Yojana (PMFBY). Once the extreme weather event has happened, to compensate for the crop damage, Ministry of Agriculture and Farmers Welfare has started

Pradhan Mantri Fasal Bima Yojana: The main highlights of the scheme are mentioned below:

- ✓ There will be a uniform premium of only 2% to be paid by farmers for all Kharif crops and 1.5% for all Rabi crops. In case of annual commercial and horticultural crops, the premium to be paid by farmers will be only 5%. The premium rates to be paid by farmers are very low and balance premium will be paid by the Government to provide full insured amount to the farmers against crop loss on account of natural calamities.

- ✓ There is no upper limit on Government subsidy. Even if balance premium is 90%, it will be borne by the Government.
- ✓ Earlier, there was a provision of capping the premium rate which resulted in low claims being paid to farmers. This capping was done to limit Government outgo on the premium subsidy. This capping has now been removed and farmers will get claim against full sum insured without any reduction.
- ✓ The use of technology will be encouraged to a great extent. Smart phones will be used to capture and upload data of crop cutting to reduce the delays in claim payment to farmers. Remote sensing will be used to reduce the number of crop cutting experiments.

Mutation Breeding

Archana M., S. Subhashini and Cholan

Abstract

Mutation breeding is a modern plant breeding technique used to create genetic variation and improve desirable traits in crops with limited natural diversity. It involves exposing seeds or plant parts to physical mutagens (like gamma rays and X-rays) or chemical mutagens (such as EMS and sodium azide) to induce heritable changes. These mutations can enhance yield, quality, disease resistance, and stress tolerance. The process includes mutagen treatment, development of M_1 and M_2 generations, and selection of useful mutants. So far, more than 3,300 mutant varieties have been developed worldwide in cereals, pulses, oilseeds, and fruits. Despite challenges like unwanted mutations and large screening needs, mutation breeding remains an important tool. With new molecular techniques like Tilling and genome sequencing, it has become more precise and efficient.

Introduction

Genetic variability is the foundation of plant breeding and crop improvement. However, in many crops, natural variation for desirable traits is limited. To overcome this, mutation breeding also known as induced mutagenesis is used to create new heritable variations through the application of physical (like X-rays, gamma rays) or chemical mutagens (like EMS).

Definition: Mutation breeding (also called induced mutagenesis) is a plant breeding technique in which mutations are artificially induced using physical or chemical agents to create new genetic variations. These variations are then screened and selected for desirable traits such as higher yield, disease resistance, stress tolerance, or improved quality.

Concept of Mutation Breeding

Mutation: A sudden heritable change in the nucleotide sequence of DNA that may alter gene function or expression.

Mutagenesis: The process of inducing mutations by applying mutagens.

Mutation Breeding: Application of induced mutations to create useful variability for crop improvement.

Types of Mutagens Used

Physical Mutagens: Gamma rays, X-rays, neutrons, and ultraviolet (UV) radiation.

Chemical Mutagens: Ethyl methane sulphonate (EMS), diethyl sulfate, 5-bromouracil, proflavin,

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sodium azide, and nitrosoguanidine.

Procedure of Mutation Breeding

Selection of Plant Material: Choose a well-adapted, high-yielding variety as the base material.

Mutagen Treatment: Expose seeds, pollen, or vegetative parts to physical or chemical mutagens.

Raising M_1 Generation: Grow treated material; most mutations are not visible yet.

Raising M_2 Generation: Screen for desirable mutants as mutations become expressed.

Evaluation and Stabilization: Confirm the stability and performance of selected mutants through further generations and field trials.

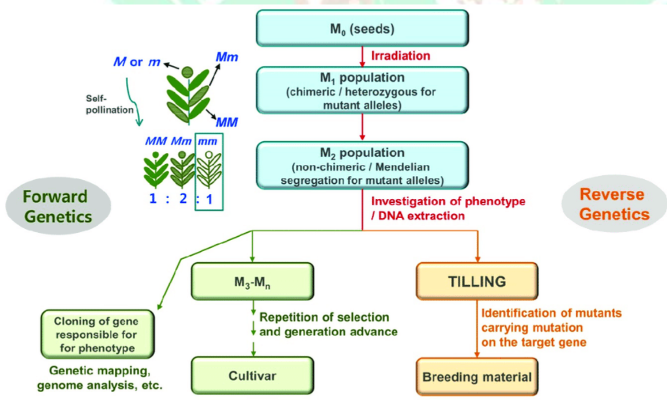
Types of Mutations

Morphological: Changes in height, leaf, or flower.

Biochemical: Alters protein or nutrient content.

Resistance: Improves tolerance to stresses or diseases.

Cytological: Involves chromosomal alterations.



Achievements of Mutation Breeding

Over 3,300 mutant varieties have been developed worldwide (IAEA, 2020) in cereals, pulses, oilseeds, fruits, and ornamentals. Examples:

Rice: Jagannath, Sharbati Sonora higher yield, disease resistance.

Wheat: Semi-dwarf mutants lodging resistance.

Barley: Golden Promise brewing quality.

Groundnut: TG-37A high oil content.

Pulses: YMV-resistant mungbean, uradbean.

Ornamentals: New flower colors in chrysanthemum and rose.

Role of International Organizations

- ✓ The Joint FAO/IAEA Division of Nuclear Techniques in Food and Agriculture has played a pivotal role in promoting mutation breeding through technical support, databases, and collaboration among countries.
- ✓ Mutant Variety Database (MVD) maintained by IAEA documents officially released mutants worldwide.

Conclusion

Mutation breeding has proven to be a vital tool in plant improvement programs, particularly when natural variability is lacking. It has contributed significantly to enhancing yield, quality, disease resistance and stress tolerance in many crops. Despite some limitations, advancements in molecular biology and mutation detection techniques (TILLING, next-generation sequencing) are making mutation breeding more precise and efficient. Thus, mutation breeding will continue to play an important role in addressing global challenges of food security, climate resilience, and sustainable agriculture.

References

Shu, Q. Y., Forster, B. P. and Nakagawa, H. (2012). Plant Mutation Breeding and Biotechnology. CABI &FAO/IAEA, Rome.

Singh, B. D. (2015). Plant Breeding: Principles and Methods (10th Edition). Kalyani Publishers, New Delhi.

Micke, A. (1991). Induced mutations for crop improvement. *Mutation Research*, 263: 189-197.

Maluszynski, M., Ahloowalia, B. S. and Sigurbjornsson, B. (1995). Application of *in vivo* and *in vitro* mutation techniques for crop improvement. *Euphytica*, 85: 303-315.

IAEA. (2020). Mutant Variety Database.

Stadler, L. J. (1928). Mutations in barley induced by X-rays and radium. *Science*, 68: 186-187.

Gustafsson, A. (1940). The mutation system of the chlorophyll apparatus. Lund University Yearbook, 36: 1-40.

Micke, A. (1991). Induced mutations for crop improvement. *Mutation Research*, 263: 189-197.

Kharkwal, M. C. (2012). A brief history of plant mutagenesis. Plant Mutation Breeding and Biotechnology. CABI, pp. 21-30.

Ahloowalia, B. S., Maluszynski, M. and Nichterlein, K. (2004). Global impact of mutation-derived varieties. *Euphytica*, 135: 187-204.

Swaminathan, M. S. (1965). Role of induced mutations in plant improvement. *Radiation Botany,* 5: 3-14.

Nilan, R. A., Konzak, C. F., Wagner, J. and Legault, R. R. (1965). Effectiveness and efficiency of radiation for inducing genetic and cyto-genetic changes. *Radiation Botany*, 5: 71-89.

Stadler, L. J. (1928). Mutations in barley induced by X-rays and radium. *Science*, 68: 186-187

Jain, H. K. (2010). Plant Breeding: Mendelian to Molecular Approaches. Springer, New Delhi.

van Harten, A. M. (1998). Mutation Breeding: Theory and Practical Applications. Cambridge University Press.

Maluszynski, M., Nichterlein, K., van Zanten, L. and Ahloowalia, B. S. (2000). Officially released mutant varieties - The FAO/IAEA Database. Plant Cell, Tissue and Organ Culture, 65: 173-177.

Jain, S. M. (2010). Mutagenesis in crop improvement under climate change. *Romanian Biotechn-ological Letters,* 15(2): 88-106.

The Secret of Weed Tea Fertilizer: From Nuisance to Nutrition

Naveen Kumar, Gautam Kumar, Raj Roshan, Ravi Raj Kumar, Robin, Abhishek Kumar and Srinivasa Rao Meesala

Abstract

The most unwanted competitors of the crop fields are the weeds which can be transformed into valuable organic fertilizers through weed tea. Weed tea is an organic and natural liquid fertilizer obtained by soaking nutrient- rich weeds in water for two to three weeks, liberating several essential nutrients like nitrogen (N), phosphorus (P), potassium (K), and micronutrients. The solution after preparation can be applied as a foliar spray or soil drench to boost plant growth and soil fertility. Many common weeds such as Parthenium hysterophorus, Cynodon dactylon, Amaranthus viridis, Stellaria media, and Eichhornia crassipes act as excellent sources for preparation. This low cost and eco-friendly fertilizers reduce dependence on chemicals, improves and enhances microbial activity, and recycles agricultural waste effectively. This liquid solution is easy to prepare and sustainable and ideal practice for organic farming and home gardening, which contributes to improve soil health and environmental protection.

Introduction

During the cultivation of the crops, tackling weed has become headache for most of the farmers in India and world. Weeds are those unwanted and poisonous plants that germinate and grow in all sorts of places in fields, tucked away in garden nooks, or even anywhere around the roadsides and government buildings. Weeds often and generally considered as unwanted guest in farmers field which are typically blamed for competing with crops for the important resources applied on the field like nutrients, sunlight, space, and water. But What if these weeds are turned into a rich source of organic fertilizers, converting the existing problem into a sustainable solution (Kumar *et al.*, 2020 and Das, 2011). Weed tea is the best source of organic liquid fertilizer prepared from those unwanted weeds. Weed tea is a natural liquid fertilizer made by soaking or fermenting common weeds in water. At the time of decomposition process, these weeds release several essential nutrients such as nitrogen (N), phosphorus (P), potassium (K), and various micronutrients into the solution (Kannan *et al.*, 2019). When the nutrient enriched liquid is completely prepared, it can be mixed with water and applied as foliar spray or as a drenching application in soil, that provides easy and

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Table: 1 Common weed used to brew weed tea

Weed Name	Scientific name	Nutrient highlight	Benefit
Parthenium	*Parthenium hysterophorus*	Rich in Nitrogen	Promotes leafy growth
Bermuda grass	*Cynodon dactylon*	Rich in K and micronutrients	Enhances root growth
Chickweed	*Stellaria media*	Rich in N, P, K	Stimulates microbial growth
Amaranthus	*Amaranthus viridis*	Good source of Iron, N, K	Improves chlorophyll formation
Water hyacinth	*Eichhornia crassipes*	Good source of N, P	Excellent for compost tea

environment friendly ways to enhance the growth of the plant naturally (Subhashini and Rani, 2015).

While mixing the nutrients in water present in the weeds, that acts like a health booster for the plants. After the breaking down of the weeds, nutrients like nitrogen, potassium, and phosphorus is mixed into the water. This process of making weed tea compost solution is simple, eco-friendly, and budget friendly to improve the health of soil as well as plants. Therefore, it is necessary to give more and more emphasis on the importance of weeds instead of throwing and burning weeds, farmers can convert the unwanted plants into a powerful organic fertilizer that facilitates the growth and improvement of soil health and support the plants grow strong and healthy.

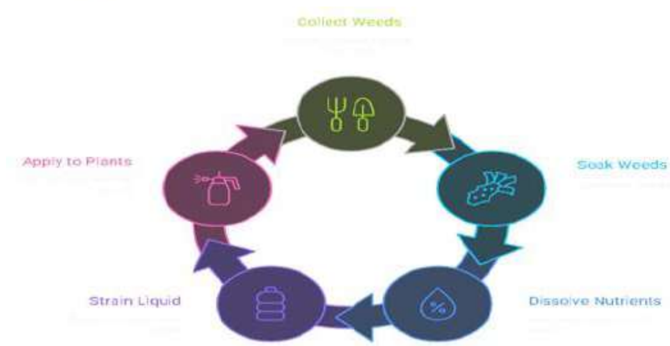
How to Make Weed Tea

Weed tea compost preparation is easy methods and following materials are required for the preparation mentioned below (Subhashini and Rani, 2015):

- ✓ A large plastic bucket or drum
- ✓ Fresh weeds (like parthenium, Bermuda grass, water hyacinth, Amaranthus viridis etc.)
- ✓ Water
- ✓ A cover or lid

Steps

- ✓ Cut the weeds into small pieces.
- ✓ Put them into a bucket and fill it with water.
- ✓ Cover the bucket with polythene and keep it in a shady spot for 2-3 weeks.
- ✓ Continuously stir the solution every day or so.
- ✓ When the appearance of water looks dark and smells strong, weed tea compost is ready.
- ✓ Straining the liquid and dilute it in a 1:10 ratio before using it.



Examples of Ingredients for Weed Tea and Their Perks

Parthenium (*Parthenium hysterophorus*): It is rich source of nitrogen, which is ideal for promoting lush, leafy growth in plants.

Bermuda grass (*Cynodon dactylon*): It is major source of potassium and beneficial micronutrients that promotes root strength and overall plant resilience.

Chickweed (*Stellaria media*): It provides a balanced supply of nitrogen, phosphorus, and potassium (NPK) and stimulating microbial activity in the soil, improving nutrient cycling.

Amaranthus (*Amaranthus viridis*): It is an excellent source of iron, nitrogen, and potassium, contributing to better chlorophyll formation and greener and healthier foliage.

Water hyacinth (*Eichhornia crassipes*): It is rich in nitrogen and phosphorus, and is predominantly active for preparing compost or liquid manure (weed tea), adding essential nutrients and improving soil fertility (Suthar and Singh, 2008).

Benefits of Weed Tea

Weed tea is gaining popularity day by day in organic agriculture for several reasons (Singh and Choudhary, 2017).

Budget-Friendly: Those weeds that are thrown unnecessary can be turned into valuable fertilizers.

Eco- Friendly: Weeds are free from chemicals, good and safe for nature, and supports soil life.

Nutrient-Dense: Weeds also acquire and possess the same nutrients that cultivated plants require.

Easy to Prepare: No such requirements of any innovation- just weeds, water, and a bit of patience.

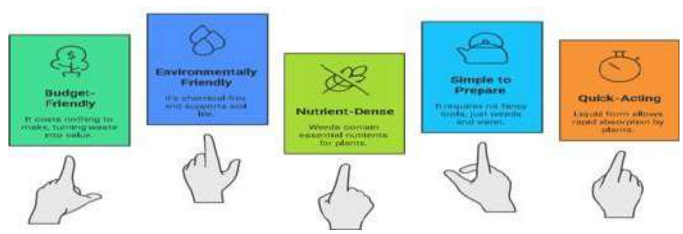
Quick-process: As we know it is a liquid, it gets absorbed quickly by the roots and leaves.

Safety Tips for Making Weed Tea

- ✓ While applying the solution, wearing gloves is necessary and mandatory because it creates skin irritation.
- ✓ Keep the bucket in a well-aerated area, as the odour can be quite strong.
- ✓ Avoid excess application and always apply the diluted mixture.
- ✓ Ensuring seeds are not present in the weeds, or they might sprout again in garden (Ramesh *et al.*, 2009).

Conclusion

The preparation of weed tea method is an easy, and yet effective organic fertilizer. It survives and thrives with nature's cycle, converting waste into nourishment. Utilizing and application of weed tea in home gardens and crop fields exemplifies sustainable approach of farming. It preserves the soil health, plants blooming and protects the environment. At last, weed tea solution signifies that even the most disregarded plants can drive incredible growth and promotes sustainability (Pimentel and Burgess, 2014).



References

Das, T. K. (2011). Weed Science: Basics and Applications. New Delhi: Jain Brothers.

Kannan, R. L., Subramani, T. and Mohanraj, R. (2019). Weeds as potential green manure and organic fertilizer sources for sustainable farming systems. *Asian Journal of Soil Science*, 14(2): 190-195.

Kumar, S., Singh, R. and Meena, R. S. (2020). Utilization of weeds as bio-fertilizer and composting material in sustainable agriculture. *International Journal of Current Microbiology and Applied Sciences*, 9(2): 1574-1582.

Subhashini, P. and Rani, D. S. (2015). Eco-friendly weed management through weed-based liquid manures. *Journal of Environmental Research and Development*, 9(3): 694-700.

Gupta, S. and Prasad, M. (2018). Role of weed biomass in improving soil fertility through organic composting. *Journal of Agroecology and Natural Resource Management*, 5(2): 100-106.

Suthar, S. and Singh, S. (2008). Feasibility of composting water hyacinth (*Eichhornia crassipes*) using earthworms (*Eisenia fetida*): Impact on nutrient enrichment. *Bioresource Technology*, 99(19): 884-890.

Singh, J. P. andChoudhary, M. (2017). Organic liquid fertilizers: A sustainable option for eco-friendly agriculture. *Journal of Pharmacognosy and Phytochemistry*, 6(5): 1337-1342.

Ramesh, P., Panwar, N. R., Singh, A. B. and Ramana, S. (2009). Organic farming: Its relevance to the Indian context. *Current Science*, 96(4): 652-654.

Pimentel, D. and Burgess, M. (2014). Environmental and economic costs of the application of pesticides primarily in the United States. *Integrated Pest Management*, 2(1): 47-71.

Role of Government Support in the Growth of Indian Agriculture

Shivam Singh, Aditya Kumar Giri and Saumya Singh

Introduction

Agriculture plays an essential role in the Indian economy. It is the main source of income for about 58% of the population within the economy. Agriculture is the backbone of rural India, providing work to a good portion of the population, even as industry and cities continue to grow. India is one of the top producers of rice, wheat, pulses, fruits, and vegetables in the world. The gross value added from the agriculture sector to gross domestic product (GDP) is around 18 to 20%. It is also an important economic sector for agro-based industries and exports, which provide additional national income and foreign exchange. Agriculture in India is also linked with food security as it ensures the country's population has a reliable source of food grains and other important products. Government programs such as PM-KISAN and MSP (minimum support price) highlight the government's desire to improve the welfare of farmers and enhance output from agriculture. Agriculture provides a larger economic picture. It influences the culture and traditions of many citizens in the country. Rituals, festivities, and the rural way of life are often incorporated into the agricultural calendar. The sector does face a number of issues challenges such as climate change, dwindling water resources, and smaller land holding. Therefore, technology and sustainable practices for agricultural activities will be a critical characteristic for the continued economic growth, and food security of India.

Supporting Indian Farmers: Important Agricultural Welfare Programs

Pradhan Mantri Kisan Samman Nidhi (PM-KISAN): The Pradhan Mantri Kisan Samman Nidhi (PM-KISAN) is a direct income support scheme inaugurated in February 2019 by the Government of India to provide financial assistance to small and marginal farmers. The program gives eligible farmers ₹6,000 per year in three equal installments of ₹2,000 directly into the farmer's bank account to help with agricultural and household expenses. The scheme grants benefits to small and marginal farmer families and was expanded to grant coverage to all families of farmers engaged in farming activities owning cultivable land irrespective of size of land holding. The PM-KISAN scheme benefits farmers by giving them an alternative to informal credit, assists in income stabilization and supports sustainable agricultural practices. The PM-KISAN scheme is implemented by the Ministry of Agriculture & Farmers Welfare through a Direct

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Benefit Transfer (DBT) mechanism which ensures payment directly into a farmer's bank account without the need of intermediaries which creates efficiency in making payments, increases transparency and streamlines registration processes. Millions of farmers have benefitted from the PM-KISAN scheme by providing financial support and enhancing a farmer's capacity to purchase goods and services, thereby providing some stability to the rural economy.

Pradhan Mantri Fasal Bima Yojana (PMFBY): The Pradhan Mantri Fasal Bima Yojana (PMFBY) is a government-sponsored crop insurance scheme that started in 2016. It is intended to protect farmers against loss of crops due to natural calamities, pest and diseases. If farmers experience crop loss due to drought, flood, hailstorm, or pest attack, the scheme may offer financial assistance. For PMFBY, farmers pay a small premium (typically 1.5% of value for *Kharif* crops, 2% of value for *Rabi* crops, and 5% of value for commercial crops), and the government subsidizes the rest of the premium. Coverage includes all food and oilseed crops, commercial crops, and horticultural crops, which are grown annually. Claims are processed in a timely manner using yield data and technology (satellite remote sensing imagery) to improve efficiency and reduce delay time. PMFBY contributes to provide steady income for farmers, gives them confidence to improve their farming practices, and decreases reliance on informal loans. It is carried out by the Ministry of Agriculture & Farmers Welfare and executed through private insurance companies, and has the objective to strengthen the resilience of the agricultural system.

Rashtriya Krishi Vikas Yojana (RKVY): The Government of India launched the Rashtriya Krishi Vikas Yojana (RKVY) in 2007 as its flagship initiative for holistic agriculture development and all its allied sectors. The main goal of the RKVY is to provide incentives to the state governments to enhance investments and also facilitate coordinated and adequately financed planning and implement-ation of various agriculture projects, enabling the farmers to earn better livelihood from agriculture while increasing production in the process. In accordance with the implementation dynamics of the scheme, funds are available to states based on performance and formulated project plans and gives the state - which has been given leadership, the flexibility of designing the plan based on specific communities needs. The activities supported under the scheme cover project funding across general activities; irrigation, soil health management, seed production, project development and infrastructure modernisation, adopting/ supporting support technologies (products) to scale together with other distribution mechanisms to either improve productivity and sustainability or both through efficiencies and on farm experimentation. The implementation of the RKVY initiative has supported rural living standards and improved food security by utilising state led Agriculture based initiative and funding for agriculture development.

The scheme is implemented by the Ministry of Agriculture & Farmers Welfare and with relevant counterpart state governments.

Soil Health Card Scheme: The Government of India introduced the Soil Health Card Scheme in 2015 as a means of encouraging sustainable agriculture through improved soil management. The Soil Health Card Scheme supports farmers by providing them with specific soil nutrient status and quality information through a "Soil Health Card." The Soil Health Card contains important information about the soil status of three major nutrients (nitrogen, phosphorus, potassium), future nutrient requirements related to micronutrients, and recommendations regarding fertilizers, including type and quantity of fertilizer use. Farmers can improve the efficiency of fertilizer use, increase crop yield, decrease input costs, and stop damaging the soil through excess or misuse of chemicals, using this information as a reference. In adddition to addressing current deficiencies, the Scheme is geared towards balanced fertilization, enhancing soil fertility, and promoting sustainable agriculture practices. The information is provided to farmers by the Ministry of Agriculure & Farmers Welfare in cooperation with state agriculture departments and soil testing laboratories across the nation. The Soil Health Card Scheme is an important element of addressing long-term sustainability in agriculture, and serves to increase farmer income.

e-NAM (National Agriculture Market): e-NAM (National Agriculture Market) is an online trading platform initiated by the Government of India in 2016. It has been established to create a unified national market for agricultural commodities. e-NAM has electronically connected various agricultural produce market committees (APMC) across the states, offering farmers the opportunity to sell their produce directly to buyers beyond their local APMCs. e-NAM is helping to improve price discovery, reduce the cost to intermediaries, and provide more transparency in the selling process. e-NAM allows farmers to view and compare prices, and get better payment for the sale of their produce, resulting in returning farmers getting better prices. Buyers have improved access to a wider diversity of quality produce that exceeds local markets. e-NAM provides electronic bidding, payment, and logistics, and e-NAM aims to enhance farmers' income by ensuring that farmers receive competitive prices, and minimizing postharvest losses. The Department of Agriculture & Farmers Welfare with the various state governments and the state APMCs are implementing e-NAM. Simply putting traditional markets online, e-NAM's mission is modernization and to build greater efficiency in the agricultural sector.

Kisan Rail Scheme: The Government of India launched the Kisan Rail Scheme in July 2020, with the objective to facilitate the speedy and efficient movement of perishable agricultural products across the country. It is aimed to help reduce post-harvest losses, and guarantee that farmers receive a better price for their produce, by connecting production centers directly with consumption centers, through refrigerated rail-rakes. Kisan Rail intends to move things like fruits, vegetables, dairy products, and other perishables, over medium to long distances, while maintaining quality, as part of an overall transportation solution. It helps farmers and traders reach larger markets especially in urban cities that are a distance from farmlands, and at considerably lower costs than traditional transportation methods. Kisan Rail operates under the auspices of Indian Railways with coordination from the Ministry of Agriculture & Farmers' Welfare, and other state governments. By improving supply chain efficiencies, and reducing spoilage, Kisan Rail aims to help increase farmers' net incomes, and thus strengthen the agricultural economy of the country.

Pradhan Mantri Dhan-Dhaanya Krishi Yojana (PM-DDKY): The Pradhan Mantri Dhan-Dhaanya Krishi Yojana (PM-DDKY) is an important scheme by the Indian government intended to improve agricultural productivity and rural welfare in 100 of the country's most backward agricultural districts. Covered under a proposed outlay of ₹24,000 crore per annum for six years starting in 2025-26, the PM-DDKY is targeted to benefit about 1.7 crore small and marginal farmers. A defining feature of PM-DDKY is its integration of 36 existing schemes into the new structure provided by 11 different Ministries to ensure a co-ordinated, integrated approach to PM-DDKY delivery with a complete package of support, which would includes quality seeds, subsidized irrigation systems, infrastructure for storage and cold chain, low-interest loans, crop insurance, training and direct market access to customers. The delivery of the PM-DDKY is going to be overseen by a National Steering Committee and local delivery will be provided by 'Dhan-Dhan Samitis' that operate at district levels, and develop baselines and plans suited to local agro-climatic conditions.

References

Ministry of Agriculture & Farmers Welfare, Government of India. (2023). Official information on agricultural schemes including PM-KISAN, PMFBY, RKVY, Soil Health Card, e-NAM, and Kisan Rail. Retrieved from https://agricoop.gov.in/

PM-KISAN official website. (2023). Pradhan Mantri Kisan Samman Nidhi scheme details. Retrieved from https://pmkisan.gov.in/

PMFBY official website. (2023). Pradhan Mantri Fasal Bima Yojana scheme information. Retrieved from https://pmfby.gov.in/

Food and Agriculture Organization (FAO). (2020). The state of food and agriculture 2020. Retrieved from http://www.fao.org/3/cb1447en/CB1447EN.pdf

Ministry of Statistics and Programme Implementation, Government of India. (2023). Economic indicators and agriculture contribution to GDP. Retrieved from http://mospi.nic.in/

Cabinet Approves the PM Dhan-Dhaanya Krishi Yojana." PM India, Prime Minister's Office, 16 July 2025, www.pmindia.gov.in/en/news_updates/cabinet-approves-the-pm-dhan-dhaanya-krishi-yojana/.

e-NAM official website. (2023). National Agriculture Market platform details. Retrieved from https://enam.gov.in/

World Bank. (2021). Agriculture and rural development data. Retrieved from https://data.worldbank.org/

Coffee Stem Borer: The Silent Killer of Coffee Plantations

M. Kabilan

Introduction

Coffee, one of the most cherished beverages worldwide, is not merely a drink but an agricultural legacy supporting millions of livelihoods across the globe. India, known for its high-quality *Arabica* and *Robusta* coffee, contributes significantly to the international coffee market. However, this valuable crop faces numerous biotic challenges that threaten its productivity and quality. Among these, the White Stem Borer (WSB) (*Xylotrechus quadripes* Chevrolat) stands out as one of the most devastating pests affecting *Arabica coffee* in India and several other coffee-growing regions. This pest, often called the "Silent Killer", causes enormous yield losses, weakens coffee bushes and in severe cases, leads to plant death. Effective management of stem borer demands a deep understanding of its biology, lifecycle and integrated control measures.

The Pest and Its Identification

The coffee white stem borer is a cerambycid beetle, belonging to the family *Cerambycidae* under the order *Coleoptera*. The adult beetle is slender, about 1.5 to 2.5 cm long, with a distinctive pattern of white and brown bands across its wing covers, giving it a striking appearance. The adult male is smaller than the female and has longer antennae. The grub (larval stage) is creamy white, legless and found tunneling inside the stem, where it causes the most damage. Since the larva remains hidden within the stem, the infestation often goes unnoticed until severe damage has already occurred.

Life Cycle of the Coffee Stem Borer

Understanding the pest's lifecycle is crucial for timely intervention.

Egg Stage: The female beetle lays eggs singly or in small clusters in crevices of the bark, mostly on the main stem or thick branches. A single female can lay up to 50-100 eggs during her lifetime.

Larval Stage: The larvae hatch within 7-12 days and bore into the stem, feeding on the inner tissues. This stage lasts for 6-10 months, depending on climatic conditions. The grub tunnels through the woody tissues, disrupting water and nutrient flow and weakening the plant structure.

Pupal Stage: After completing the feeding period, the larva pupates within the tunnel. The pupal stage lasts around 3-4 weeks.

Adult Emergence: Adults emerge through round exit holes, leaving behind frass and sawdust. The beetles are most active during March-May and October-December, coinciding with the post-harvest and monsoon periods.

The pest completes one or two generations per year depending on environmental conditions, particularly temperature and humidity.

Nature and Symptoms of Damage

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The initial symptoms of stem borer attack are subtle and often overlooked. As the larvae tunnel inside, they interfere with the plant's vascular system. Over time, visible signs become apparent:

- ✓ Yellowing of leaves and premature leaf fall.
- ✓ Drying of twigs and reduced flowering.
- ✓ Wilting of the entire plant in severe cases.
- ✓ Presence of round exit holes (about 5-8 mm in diameter) on the main stem or branches.
- ✓ Sawdust-like frass deposits near the holes, especially at the base of the plant.

When the pest population is high, entire coffee blocks can be destroyed, particularly in *Arabica* plantations grown at lower elevations with higher temperatures.

Factors Favoring Infestation

Climatic Conditions: Warm temperatures (above 28°C) and prolonged dry spells promote adult emergence and activity.

Poor Shade Management: Coffee grown under inadequate or excessive shade becomes vulnerable to pest infestation.

Neglected Pruning and Sanitation: Dead and infested stems left in the field serve as breeding grounds for beetles.

Susceptible Varieties: *Arabica coffee* varieties such as *S.795, Cauvery and Kent* are more prone to attack compared to *Robusta*.

Economic Impact

The coffee stem borer is one of the most economically significant pests of *Arabica coffee* in India, Sri Lanka, Myanmar and parts of Africa.

Infestation levels can range from 5% to over 50%, depending on management practices and environmental conditions. The pest not only reduces yield but also affects the longevity and productivity of plantations, forcing replanting and leading to major economic losses. In India, annual losses due to WSB are estimated to run into crores of rupees, especially in the coffee tracts of Karnataka, Kerala and Tamil Nadu.

Management Strategies

Managing coffee stem borer requires an Integrated Pest Management (IPM) approach combining cultural, mechanical and biological measures along with selective use of chemicals.

Cultural Practices

Proper Shade Regulation: Maintain balanced shade with 50-60% canopy cover to reduce beetle activity.

Timely Pruning: Prune infested and dead branches to prevent the pest from breeding.

Stem Scraping: Remove loose bark and moss to expose cracks where eggs are laid.

Regular Monitoring: Inspect fields during adult flight periods (March-May and October-December) to identify fresh attacks.

Mechanical Control

Manual Removal: Infested plants or stems should be uprooted and burnt immediately to destroy larvae and pupae.

Use of Pheromone Traps: Installation of synthetic sex pheromone traps (lure: *male aggregation pheromone*) at 4-6 traps ha^{-1} helps in capturing adults and monitoring population levels.

Biological Control

Natural Enemies: Predators such as *Clerid beetles* (*Enoplium sp.*) and parasitoids like *Phoracantha semipunctata* play a natural role in controlling the pest.

Entomopathogenic Fungi: Soil application of *Beauveria bassiana* or *Metarhizium anisopliae* formulations has shown promise in reducing grub populations.

Chemical Control

Chemical measures should be adopted judiciously and as a last resort:

Swabbing of Stems: Application of 10% lime wash fortified with chlorpyriphos (0.04%) or neem oil (2%) helps deter egg laying.

Targeted Spraying: Use of insecticide sprays during the peak adult emergence period can suppress beetle populations. However, excessive use may harm beneficial organisms and the environment.

Host Resistance and Replanting

Planting *Robusta coffee* or tolerant *Arabica* selections in high-risk areas can help reduce long-term losses. Regular rejuvenation and replanting with resistant or mixed varieties maintain field health and sustainability.

Conclusion

The Coffee Stem Borer continues to challenge coffee farmers across India, silently eroding plantation productivity. However, through vigilant monitoring, integrated pest management and scientific intervention, its menace can be effectively curtailed. Farmer awareness, coupled with the adoption of eco-friendly and region-specific strategies, holds the key to sustainable coffee production. A balanced ecosystem with good shade, healthy soil and regular field sanitation is the best natural defense against this pest. Ultimately, protect-ing coffee from stem borer is not just about saving a crop it is about preserving the livelihood, heritage and aroma that define India's coffee culture.

References

Veeresh, G. K. (1986). *White Stem Borer of Coffee in India*. Coffee Board of India, Bangalore.

Hall, D. R., Cork, A. and Pham, K. T. (2006). Pheromones of the coffee white stem borer, *Xylotrechus quadripes*. *Journal of Chemical Ecology*, 32(10): 2145-2159.

Reddy, P. P. and Singh, S. (2010). *Integrated Pest Management for Tropical Crops*. Springer, New Delhi.

Coffee Board of India (2024). *Annual Report on Coffee Pest and Disease Management*. Bengaluru: Coffee Research Division.

Nagesha, G. and Manohar, S. H. (2022). Recent advances in the management of coffee white stem borer. *Indian Coffee Journal*, 86(9): 12-19.

Soil Management: An Important Aspect for Sustainable Farming

Radheshyam Ramkrishna Dhole and Manisha Patel

Abstract

A sustainable farming system should be considered a management system that uses inputs, whether produced on the farm or purchased externally, most efficiently to maximize the productivity and profitability from the operation while minimizing their adverse effects on the quality of soil and water and keeps it buffered against risks. Soil management is applying operations, practices and treatments to protect soil and enhance its performance (such as soil fertility or soil mechanics). It includes soil conservation, soil amendment and optimal soil health. In sustainable agriculture, soil management plays a vital role in keeping soil healthy and preventing agricultural land from becoming poorly productive.

Introduction

Sustainable farming is the successful management of resources for agricultural production which satisfy the needs of society today while maintaining or enhancing the quality of the environment and conserving natural resources. A farming system can be considered sustainable if it ensures that "today's development is not at the expense of tomorrow's development prospects" (World Commission on Environment and Development, 1987). No farming system will be sustainable unless the soil which forms its pivot and is the essential natural resource is managed scientifically to meet the present and future needs, its productivity and quality are maintained continuously. Thus, there is no reduction of output with inputs.

The important aspects of sustainable farming are:

- ✓ Meeting the developing needs of today and tomorrow without deceleration of growth rate with constant inputs.
- ✓ Economic viability and enhanced productivity,
- ✓ Successful management of resources internal or external, renewable or non-renewable.
- ✓ Maintenance, preferably enhancement, of quality of environment, and
- ✓ Conservation of natural resources of soil and water (Kanwar, 2012)

Equation of Agricultural Sustainability

Agricultural sustainability may be defined as a function described by equation- (Lal, 1994):

$$\text{Agricultural sustainability} = d\,(P_t \times S_p \times W_t \times C_t)$$

where, Pt is the productivity potential with input of the limiting or non-renewable resource; S_p is

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the measure of critical soil property, i.e., rooting depth, soil organic matter content, cation exchange capacity; W_t is the plant available water resource and quality; Ct is the climatic factor with reference to evaporation and soil temperature flux of radioactive gases. Thus, it is a product of numerous parameters affecting productivity and sustainability.

Need of Soil Management for Sustainable Agriculture: Main component of sustainable agriculture is SOIL. If we look worldwide there is depletion of soil quality, land resources, occurrence of land degradation, climate change and global warming. Application of operation and practices, particularly site-specific treatment to protect or enhance soil health for today and for future on sustainable basis is crucial. The site-specific soil management practices adopted in sustainable farming that reduces the soil health threats with respect to soil organic matter, nutrient mining, fertility, erosion, problematic soil formation, pollution or heavy metal contamination is sustainable soil health management.

Soil Management for Sustainable Farming

- ✓ Integrated Nutrient Management
- ✓ Minimum or reduced or zero tillage instead of conventional tillage
- ✓ Legume based crop rotation
- ✓ Mulching
- ✓ Crop residue management
- ✓ Proper grazing management (Rotational grazing)
- ✓ Scientific water management

The management practices that improve and protect basically soil quality (physico-chemical and biological condition of soils) and meet needs of plants with respect to nutrients, water, oxygen, soil physical conditions for germination, growth of plumule and radicle, root system and its support and also satisfy the goals of sustainable agriculture. Moreover, the application of botanical and microbial based pesticides, particularly insecticides and herbicides should be positively initiated and adopted as their half-life and waiting period is of few days only and hence its degradation rate in soil is high and would not cause any long term residual problem in soil that further encourage the long-term sustainable development of soil.

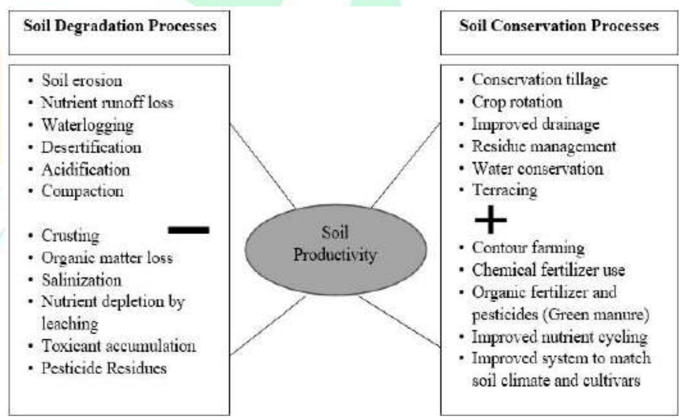

Fig. 1: Relationship between soil degradation processes and soil conservation practices

Soil Management in Present Scenario

With better soil management, farmers can fight climate change and make agriculture more sustainable. With regenerative farming, farmland can be used to capture atmospheric carbon. The idea that farmers can capture carbon and improve their bottom lines simultaneously is gaining ground in the agriculture community and among business leaders as well as policymakers. They would like to pay farmers for adopting conservation practices, such as using cover crops and reduced till methods, that take carbon from the atmosphere and store it, presumably for centuries, in the soil. Proponents say that the large-scale adoption of so-called carbon farming can transform the industry from a greenhouse gas emitter to a global carbon absorber. One-way farmers can get paid is to sell carbon credits for each metric ton of CO_2 equivalent they sequester. Private marketplaces for those credits are emerging now, and while their methodologies for verifying carbon practices and certifying credits appear robust, they are not all the same (Bomgardener *et al*. 2021).

Conclusion

To achieve food security in future, the management of soil sustainability will be a challenge through site specific nutrient management and appropriate soil conservation practices. The research will be required to avoid further degradation of soils through erosion or contamination and produce safe, sufficient and nutritious food for healthy diets.

References

Bomgardener M. M. and Britt E. E. (2021) Replenishing depleted soil with carbon dioxide from the air can combat climate change, if science, policy and markets align. *Chemical & Engineering News*

Can soil help solve our climate problem? | California State Scientists. (2021). Retrieved 14 August 2021, from https://calscientists.org/can-soil-help-solve-our-climate-problem/

Kanwar, J. S. (2012) Fundamentals of Soil Science, Revised edition, Indian Society of Soil Science, New Delhi. pp 693.

Lal, R. (1994) *Soil Conservation: Stressed Ecosystem and Sustainable Agriculture* (S.M. Virmani, J.C. Katyal, H. Eswaran and I. P. Abrol, Eds), Oxford & IBH Publishing Co., New Delhi.

World Commission on Environment and Development (1987) *Our Common Future.* Oxford University Press, UK.

Insect Pollinators and Food Security: Challenges and Conservation

Radheshyam Ramkrishna Dhole and Manisha Patel

Why pollinators matter for food security

Crops that rely on animal pollinators include fruits (apples, mangoes, berries), many vegetables (pumpkin, cucumber, tomato to varying extents), oilseeds (canola), nuts (almonds), and numerous forage and medicinal plants. Even modest reductions in pollination can shrink fruit set, lower seed quality and size, and reduce marketable yields effects that disproportionately hurt smallholder farmers and consumers who depend on nutrient-dense foods. Beyond direct crop impacts, pollination supports wild plant communities that stabilize soil, cycle nutrients and provide habitat for beneficial insects and wildlife, creating positive feedbacks for production systems.

Major challenges facing insect pollinators

Pollinator populations worldwide face multiple, often interacting threats:

Habitat loss and fragmentation: Conversion of diverse landscapes into intensive monocultures, urban sprawl and removal of hedgerows reduce floral resources and nesting sites. Fragmentation isolates populations and reduces genetic exchange.

Pesticide exposure: Both lethal and sublethal effects from insecticides (including neonicotinoids and pesticide mixtures) impair navigation, foraging, reproduction and immune function in bees and other insects.

Diseases, parasites and invasive species: Pathogens (e.g., viruses, *Nosema spp*.), Varroa mites in honey bees, and invasive insects or plants alter host-parasite dynamics and can devastate local pollinator communities.

Climate change: Altered temperature and precipitation patterns shift flowering times and insect life cycles, producing phenological mismatches between plants and pollinators and forcing range shifts that can reduce effective pollination.

Nutrition stress and landscape simplification: Reduced floral diversity yields poor nutritional resources for pollinators, weakening their resilience to other stressors.

These threats are synergistic: for example, a nutritionally stressed bee exposed to pesticides and a novel pathogen faces far higher mortality than from any single stressor. The breadth and intensity of drivers have produced documented declines in abundance and diversity for many pollinator taxa, raising red flags for ecosystem services and food production.

Consequences for agriculture and nutrition

Declines in pollination services can translate

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into lower yields, reduced quality (shape, weight, nutritional content), and higher production costs as farmers compensate with hand pollination or altered management. Some regions and crops are particularly vulnerable: specialty crops (nuts, many fruits, vegetables, coffee, cocoa) often require animal pollination for full productivity and are economically and nutritionally important for both local and global markets. Additionally, because pollinator-dependent crops frequently provide essential micronutrients, pollinator loss is a hidden nutritional threat, potentially exacerbating micronutrient deficiencies.

Conservation and management strategies

Effective responses combine on-farm practices, landscape planning and policy instruments. Key measures include:

Habitat restoration and diversification: Creating flower strips, field margins, hedgerows and maintaining semi-natural habitats increases continuous floral resources and nesting sites across seasons.

Pesticide stewardship: Reducing overall pesticide use, adopting integrated pest management (IPM), switching to less harmful products, and applying chemicals at times that minimize pollinator exposure (e.g., not during bloom) reduce acute and chronic impacts.

Supporting managed pollinators responsibly: Honey bees and commercially reared pollinators can supplement services but must be managed to avoid disease spillover to wild pollinators and to preserve genetic diversity.

Monitoring and research: Long-term monitoring programs and standardized assessment protocols help detect trends, evaluate interventions and prioritize areas for action. FAO and other agencies have developed guidelines and protocols to support monitoring and local action.

Policy and incentives: Agri-environment schemes, payments for ecosystem services, and regulations that restrict the most harmful pesticide uses encourage farmers to adopt pollinator-friendly practices. International cooperation and local tailoring of policies maximize effectiveness.

Practical examples and successes

Landscape-scale programs that combine floral resource enhancement with reduced pesticide use have improved pollinator abundance and crop yields in many contexts. Farmer participatory programs that link economic incentives to biodiversity outcomes for example, payments for planting cover crops or maintaining flower strips show promise in aligning livelihoods with conservation goals. International collaborations led by organizations such as FAO and the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) have helped countries develop national pollinator strategies and monitoring frameworks.

Conclusion

Insect pollinators are essential but vulnerable partners in food production. Their decline would not only reduce quantities of many crops but would threaten dietary diversity and nutrition, with disproportionate effects on vulnerable communities.

The problem is solvable if action is taken at multiple scales: protecting and restoring habitats, adopting pollinator-friendly agricultural practices, regulating and reducing harmful chemicals, monitoring populations, and supporting research and policy that balance production with biodiversity. Investing in pollinator conservation is an investment in resilient, nourishing and equitable food systems.

References

FAO - Global Action on Pollination Services for Sustainable Agriculture. FAO.

IPBES (2016) - Pollinators, pollination and food production: Summary for policymakers.

Potts, S. G., *et al*. (2010). Global pollinator declines: trends, impacts and drivers. *Trends in Ecology & Evolution.*

Guzman, L. M., *et al.* (2024). Impact of pesticide use on wild bee distributions across the globe. Nature Sustainability.

Devkota, K., *et al.* (2024). The impact of pollinator decline on global protein production. (Recent review on pollinators and protein crops).

FAO. The Pollination of Cultivated Plants (compendium).

Seed Science without Borders: Global Innovations for Sustainable Agriculture

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Abstract

Seed science is essential for global food and nutrition security, as it enhances seed quality, germination, and longevity through research, innovation, and supportive policies. International organizations such as the FAO, OECD, ISTA, and UPOV have developed global standards to harmonize seed trade, testing, and certification. Advances in biotechnology, molecular genetics, and precision seed enhancement have transformed seed systems worldwide. International collaboration remains vital to ensure sustainable seed production, fair trade, and the conservation of genetic diversity for resilient agriculture in the future.

Introduction

Seeds are the backbone of agriculture, directly influencing crop productivity, quality, and sustainability. Seed science covering seed physiology, technology, testing, and certification has evolved into a global discipline combining biological research, technology, and policy frameworks. With increasing challenges such as climate change, population growth, and declining natural resources, robust international seed systems are critical for food security and agricultural innovation. At the international level, seed science relies on cooperation among institutions, harmonized regulations, and cutting-edge research. Its goals include improving seed germination and vigour, maintaining genetic purity, and enabling standardized global seed exchange. This ensures farmers worldwide have access to high-quality seeds adapted to diverse agro-climatic conditions

Global frameworks and organizations in seed science

International Seed Testing Association (ISTA): Established in 1924, ISTA plays a pivotal role in developing and publishing internationally recognized rules for seed testing. It standardizes seed sampling, purity analysis, germination, and moisture determination methods to ensure uniformity across countries. Accredited laboratories under ISTA provide reliable results that support global seed trade and quality assurance.

Organisation for Economic Co-operation and Development (OECD) Seed Schemes: The OECD Seed Schemes provide a framework for certifying the varietal identity and purity of seeds intended for inter

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national trade. These schemes promote transparency and consistency among member nations, enabling farmers and seed companies to participate in the global market with confidence.

Food and Agriculture Organization (FAO): FAO works toward strengthening global seed systems, especially in developing countries, by supporting seed policy formulation, genetic resource conservation and capacity building. It emphasizes seed security during crises and promotes the use of locally adapted varieties that contribute to sustainability.

International Union for the Protection of New Varieties of Plants (UPOV): UPOV, established in 1961, provides an international legal framework for protecting plant breeders' rights (PBR). It encourages the development of new plant varieties and ensures that breeders are rewarded for their innovation, stimulating research and private sector participation in seed improvement.

Advances in international seed science

Genomic and molecular marker technologies: DNA-based tools such as SSRs, SNPs, and RAPDs help assess genetic purity, hybrid vigour, and varietal identity, supporting breeding, certification, and intellectual property protection (Walters and Engels, 2021; UPOV, 2023). Next-generation sequencing enables gene mapping for seed dormancy, germination, and stress tolerance.

Genetic engineering and CRISPR applications: Precision tools like CRISPR-Cas9 allow targeted modification of genes controlling seed size, nutrition and disease resistance, enhancing crop performance while reducing chemical inputs.

Seed priming and coating: Techniques such as priming, coating, pelleting, and encapsulation improve germination, handling, and early vigour. They also allow integration of beneficial microbes and bio-stimulants to enhance stress resilience.

Nanotechnology and biopolymer coatings: Nanomaterials and biopolymer coatings enable controlled release of nutrients, hormones, and antifungal agents, increasing seed longevity and field performance while minimizing environmental impact.

Cryopreservation and genetic resource conservation: International seed science has also made remarkable progress in seed storage and conservation. Cryopreservation, which involves storing seeds at ultra-low temperatures (-196°C) using liquid nitrogen, allows long-term preservation of genetic material without loss of viability. Global seed banks such as the Svalbard Global Seed Vault in Norway safeguard over one million seed samples, ensuring genetic diversity against natural or human-induced threats.

Digital seed banks and bioinformatics: Digitalization has transformed seed conservation. Bioinformatics platforms now catalogue seed traits, genomic data, and germination profiles, enabling easy access to genetic resources across continents. Through global networks like Genesys and CGIAR Gene banks, researchers can exchange data to strengthen breeding programs and ensure equitable benefit-sharing of plant genetic resources.

Standardization through ISTA and OECD schemes: International organizations such as ISTA and OECD have harmonized seed testing and certification protocols, ensuring consistency and reliability in global seed trade. ISTA's International Rules for Seed Testing (2022) provide uniform procedures for purity, germination, and vigour testing, while OECD Seed Schemes facilitate varietal certification across member countries.

Digital and automated seed testing: AI, machine vision, and automated analyzers now assess seed traits like size, shape, colour, and viability more quickly and accurately. Non-destructive vigour analyses, including electrical conductivity and chlorophyll fluorescence, help determine seed quality.

Adapting to environmental stresses: Climate-resilient seeds are being developed to withstand heat, drought, and salinity, with traits like improved antioxidant activity and regulated dormancy for better germination under stress.

Role of phytohormones and ROS in stress tolerance: Research on ABA, GA, ethylene, and reactive oxygen species helps design seeds with enhanced resilience, a priority for sustaining food production under variable environments.

Global seed policy harmonization: Organizations like FAO and OECD provide frameworks for seed quality assurance, varietal registration, and phyto-sanitary measures to facilitate cross-border seed trade.

Plant Breeders' Rights (PBR) and UPOV framework: The UPOV Convention, 1961 plays a central role in protecting new plant varieties and breeders' innovations. It encourages investment in seed research and ensures fair compensation for intellectual property, thereby promoting innovation while balancing farmers' rights.

Public-private partnerships in global seed systems: Collaborations between governments, industry, and research institutions expand seed access and foster technology exchange. PPPs support seed analytics platforms, mobile certification, and traceability tools for transparent, high-quality seed systems.

Future prospects in international seed science

The future of seed science lies in biotechnology, data analytics, and sustainability. AI-assisted breeding, blockchain traceability, and IoT monitoring are set to transform the seed value chain. Emerging areas include;

- ✓ Synthetic seeds and artificial encapsulation for high-value crops
- ✓ Metabolomics and proteomics to study seed aging
- ✓ Digital twins for simulating seed performance
- ✓ Climate-smart seed banks with renewable energy and smart sensors

International cooperation in research, policy, and training will be key to meeting the growing demand for quality seeds. ISTA, FAO, and other organizations are actively strengthening human capacity through workshops, certification programs, and digital knowledge platforms.

Conclusion

International seed science integrates research, innovation, and collaboration to improve agricultural outcomes. Organizations like ISTA, OECD, FAO, and UPOV have established standards, promoted fair trade, and safeguarded genetic resources. Advances in genomics, biotechnology, seed enhancement, and digital tools are bridging science and practical farming, enabling the production of high-quality, stress-tolerant, and genetically diverse seeds. However, challenges remain in ensuring equitable seed distribution, protecting biodiversity, and addressing climate change. Meeting these requires strengthened global partnerships, ongoing research, and sustainable technologies. Ultimately, the future of agriculture depends on using seed science not just to boost productivity, but to safeguard food systems and preserve genetic diversity for generations to come.

Trichoderma and Climate Change: Adapting Agriculture to a Warming World

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Abstract

Climate change poses severe threats to global agriculture, with rising temperatures, droughts, and soil salinization reducing crop yields and threatening food security. *Trichoderma*, a genus of beneficial soil fungi, offers a sustainable solution to enhance agricultural resilience. This article explores Trichoderma's role in adapting farming to a warming world, drawing on recent research. By forming symbiotic relationships with plant roots, *Trichoderma* boosts nutrient uptake, produces defensive enzymes, and enhances antioxidant systems, enabling crops to withstand environmental stresses. Studies demonstrate its efficacy in mitigating drought, heat, and salinity, with treated plants showing up to 50% higher yields and 70% less damage under combined stresses. From Indian rice fields to Australian tomato farms, *Trichoderma* applications reduce water use, protect against heatwaves, and reclaim salinized soils. Its affordability and ease of use make it a scalable tool for smallholder and commercial farmers alike. By reducing reliance on chemical inputs and boosting ecosystem health, *Trichoderma* paves the way for climate-resilient agriculture, ensuring sustainable food production in an increasingly unpredictable world.

Introduction

The world is heating up, and agriculture is feeling the burn. From blistering heat waves in Europe to prolonged droughts in sub-Saharan Africa, climate change is reshaping the way we grow food. By 2050, global crop yields could plummet by 10-25% due to rising temperatures, erratic rainfall, and salinized soils from rising seas (Kashyap *et al*., 2017). Farmers, already grappling with feeding a projected 10 billion people, face a daunting task: adapt to a harsher, less predictable environment without leaning on chemical crutches that harm ecosystems. Yet, beneath our feet lies a powerfully *Trichoderma*, a group of soil-dwelling fungi that could revolutionize farming in a warming world. These unassuming microbes are no strangers to soil. Found naturally across diverse ecosystems, *Trichoderma* species form symbiotic partnerships with plant roots, acting as both protectors and nurturers. They fend off pathogens, unlock vital nutrients like nitrogen and phosphorus, and bolster plant defenses against abiotic stresses like drought and heat (Brotman *et al*., 2013). Unlike synthetic fertilizers or pesticides, which contribute to green-house gas emissions, *Trichoderma* offers a green alternative. It enhances crop resilience without genetic modification, making it accessible to farmers from smallholder plots in India to industrial fields in

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California. What makes *Trichoderma* a game-changer is its ability to tackle multiple climate-driven challenges at once. Research shows it mitigates drought by improving water uptake, counters heat stress with antioxidant boosts, and even detoxifies salty soils a growing issue as seawater creeps into farmlands (Senizza *et al*., 2023). In trials, *Trichoderma*-treated crops like rice and tomatoes have shown yield increases of 20-50% under stress, offering hope for regions hit hardest by climate shifts. Affordable and easy to apply through seed coatings or soil drenches, these fungi are already transforming farms in places like Bangladesh and Australia. This article dives into how *Trichoderma* is paving the way for climate-resilient agriculture. From drought-proofing crops to shielding them from scorching summers and salty soils, we'll explore the science and real-world impact of these fungal superheroes. As we race against climate tipping points, *Trichoderma* reminds us that nature often holds the keys to survival if we're willing to dig a little deeper.

Fig. 1: *Trichoderma* fungal culture plate displaying dense green and white mycelial growth

Meet the Fungal Superheroes: Unlocking *Trichoderma*'s Power

Imagine a world where soil teems with invisible guardians that shield crops from climate chaos. That's *Trichoderma* a genus of beneficial fungi found naturally in healthy soils worldwide. Unlike harmful pathogens, these fungi form symbiotic bonds with plant roots, acting like a personal bodyguard and nutrient delivery service. *Trichoderma* species excel at breaking down organic matter, releasing essential nutrients like phosphorus and nitrogen that plants crave during stress. They also produce enzymes that fend off disease-causing microbes, reducing the need for chemical pesticides. But their true magic shines in a warming world. As global temperatures rise, extreme weather stresses plants' natural defenses. *Trichoderma* steps in by boosting the plant's antioxidant systems chemical shields that neutralize harmful free radicals caused by heat or drought.

Research highlights *Trichoderma*'s versatility for "climate-resilient agriculture," where it enhances crop survival across diverse environments, from arid farms in India to saline fields in the Middle East. In lab and field trials, treated plants show 20-50% higher yields under stress. Farmers in drought-prone regions are already spraying *Trichoderma* formulations on seeds, turning vulnerable crops like wheat and tomatoes into hardy survivors. It's affordable, eco-friendly, and scales easily no high-tech labs required.

Drought Defense: Quenching Thirst in a Drying

World

Droughts are the silent killers of modern agriculture, sucking moisture from soil and leaving fields cracked and barren. By 2050, two-thirds of the world's farmland could face severe water shortages, threatening billions. Enter *Trichoderma*, the ultimate water-saver. These fungi colonize plant roots, forming a network that improves water uptake efficiency. They trigger hormonal signals in plants, closing leaf pores during dry spells to conserve moisture while maintaining photosynthesis. A groundbreaking study on the model plant *Arabidopsis thaliana* revealed that *Trichoderma* inoculation slashed drought damage by activating stress-response genes, leading to healthier roots and greener leaves (Senizza *et al*., 2023). In real farms, this translates to action. Indian rice farmers using *Trichoderma*-treated seeds reported 30% less water use and 25% higher harvests during the 2022 monsoon failure (Kashyap *et al.*, 2017). The fungi also enhance soil structure, creating sponge-like pockets that hold water longer. Picture a cornfield in California's parched Central Valley: Untreated plants yellow and die, but *Trichoderma*-boosted ones stand tall, their roots delving deeper for hidden moisture. This isn't sci-fi it's scalable biotech, with commercial products like "TrichoShield" already hitting markets for under $10 per acre.

Heat Wave Warriors: Cooling Crops Amid Rising Temperatures

Summers are getting hotter, with heatwaves frying crops like never before. Wheat in Europe baked at record highs in 2023, slashing yields by 15%. Plants overheat, proteins denature, and growth stalls. *Trichoderma* counters this by revving up the plant's cooling systems. The fungi produce heat-shock proteins molecular chaperones that refold damaged cell parts and ramp up antioxidants like superoxide dismutase. In experiments, *Arabidopsis* plants doused with *Trichoderma* endured 35°C (95°F) blasts with minimal wilting, their chlorophyll levels holding steady (Senizza *et al.*, 2023). Combined with drought, the fungi's effects doubled: Plants survived "heat-drought combos" that mimic future climate scenarios, showing 40% better bio-mass. Field stories abound. In Australia's sunburnt outback, tomato growers sprayed *Trichoderma* biofertilizers, boosting fruit set by 35% during 40°C spikes (Kashyap *et al*., 2017). The fungi even tweak root architecture for better airflow and shade, naturally cooling soil by 2-3°C. As climate models predict 2°C global warming by 2040, *Trichoderma* offers a buffer think of it as air conditioning for your crops, powered by soil microbes.

Salty Soil Saviors: Thriving in a Salinized Land-scape

Sea levels are rising, irrigation water grows saltier, and 20% of irrigated lands worldwide are now too saline for farming. Salt buildup poisons roots, halting nutrient flow and causing "salt stress." *Trichoderma* flips the script by detoxifying soils and fortifying plants. During root colonization, *Trichoderma* slips past the plant's early alarm systems avoiding immune triggers that would expel

Table 1: Mechanisms of *Trichoderma*-Mediated Abiotic Stress Tolerance in Plants

Stress Type	Physiological Response	*Trichoderma* Action	Associated Plant Response
Drought	Reduced water availability	Enhances root growth and water uptake	Upregulation of drought-responsive genes
Heat	Protein denaturation, oxidative stress	Induction of heat shock proteins and antioxidant enzymes (e.g., SOD, CAT)	Maintains chlorophyll levels and photosynthesis
Salinity	Na^+ toxicity, osmotic imbalance	Promotes salt ion efflux and osmolyte accumulation	Reduced Na^+ uptake, higher auxin synthesis
Combined stress	Synergistic negative effects on plant physiology	Simultaneous activation of antioxidant, hormonal, and microbiome-associated pathways	Greater biomass retention and survival under stress

invaders. Instead, it activates antioxidant pathways, mopping up toxic ions like sodium. A pivotal study showed *Trichoderma*-colonized *Arabidopsis* roots expelling 50% more salt while boosting growth hormones like auxin (Brotman *et al*., 2013). Plants gained “saline stress tolerance,” with 60% higher survival in salty conditions. In coastal Bangladesh, where salinity ruined 1 million hectares of rice paddies in 2023, *Trichoderma* applications restored yields to pre-flood levels (Kashyap *et al*., 2017). The fungi solubilize salt-bound nutrients, making them plant-available and even produce osmoprotectants natural antifreeze-like compounds that stabilize cells. For veggies like cucumbers in Israel's Negev Desert, this means bumper crops on “dead” land. Commercial sprays, mixed with compost, cost pennies and last seasons, turning salty wastelands into green goldmines.

Synergy in Stress: Tackling Combined Climate Threats

Climate change doesn't strike singly droughts pair with heat, salts mix with floods. *Trichoderma*'s genius lies in its “holobiont” approach: It strengthens the entire plant-microbe ecosystem. The 2023 *Arabidopsis* study proved it: Under combined heat-drought, *Trichoderma* mitigated 70% of damage by syncing fungal and plant defenses, preserving the root microbiome (Senizza *et al.*, 2023).

Conclusion

Trichoderma isn't a silver bullet, but it's a game-changer for adapting agriculture to our warming world. From drought-proof roots to heat-resistant leaves and salt-tolerant fields, these fungi empower farmers to feed 10 billion people by 2050 without ravaging the planet. Studies confirm: Widespread adoption could cut chemical inputs by 40%, boost yields 25%, and slash emissions. The call to action is clear governments, seed companies, and farmers must scale *Trichoderma* tech now. In India, national programs distribute it free to smallholders; the EU funds biofactory startups. Imagine vineyards in scorched Spain or rice paddies in flooded Vietnam, all thriving thanks to soil's unsung heroes. As we face climate tipping points, *Trichoderma* reminds us: Solutions often hide in plain sight, right under our feet. By harnessing these fungal allies, we don't just adapt we innovate a greener, more resilient food system. The warming world awaits its saviors let's grow with *Trichoderma*.

References

Kashyap, P. L., Chakraborty, B. N. and Kumar, S. (2017). *Trichoderma* for climate resilient agriculture. *World Journal of Microbiology and Biotechnology*, 33(8): 155.

Senizza, B., Chitarrini, G., Bravetti, L., Negri, S., Folloni, S., Beone, G. M., Lucini, L. and Rouphael, Y. (2023). *Trichoderma spp.*-mediated mitigation of heat, drought, and their combination on the *Arabidopsis thaliana holobiont*. *Frontiers in Plant Science*, 14: 1190304.

Brotman, Y., Landau, U., Cuadros-Inostroza, Á., Takayuki, T., Fernie, A. R., Chet, I. and Viterbo, A. (2013). *Trichoderma*-plant root colonization: Escaping early plant defense responses and activation of the antioxidant machinery for saline stress tolerance. *PLoS Pathogens*, 9(3): e1003221.

The Science and Significance of Onion Tissue Culture

Vengatesh M., Nivetha A. L. and Shridevi S.

Tissue culture, also known as micro propagation, represents a cornerstone of modern agricultural biotechnology. When applied to the onion (*Allium cepa* L.), a globally significant vegetable crop, it transforms traditional propagation methods into a sterile, controlled, and highly efficient process. This technique, while complex and requiring specialized facilities, offers unparalleled advantages in rapid multiplication, disease control, and genetic uniformity, making it a powerful tool for modern agriculture and plant breeding.

The Core Principles and Process of Onion Micro propagation

The success of onion tissue culture hinges on the principle of totipotency the ability of a single plant cell to regenerate into a whole, complete plant. The process is a carefully orchestrated sequence of steps, conducted under strictly aseptic conditions to prevent contamination, which is the primary threat to any tissue culture operation.

Explants Selection and Sterilization

The journey begins with selecting a suitable piece of tissue, known as an explants, from a healthy “mother” onion bulb. The most effective explants for onion are typically the basal plate (the compressed stem at the bottom of the bulb where roots emerge) or shoot tips. These tissues are rich in meristematic cells, which are actively dividing and have a high regenerative capacity. The explants is meticulously cleaned and then disinfected using sterilizing agents like a diluted sodium hypochlorite (bleach) solution. This step is critical to eliminate all surface microbes that could otherwise proliferate and destroy the culture.

Culture Initiation and Medium Composition

The sterile explants is placed on a nutrient-rich culture medium, usually a solidified gel. This medium is the lifeblood of the culture, providing all the necessary components for growth. A standard medium for onion tissue culture is typically a variation of the Murashige and Skoog (MS) medium. Its key components include:

Inorganic Nutrients: A balanced mix of essential macro- (e.g., nitrogen, phosphorus, potassium) and micro-nutrients (e.g., iron, zinc, manganese).

Energy Source: A carbohydrate source, most commonly sucrose, which provides the energy for cell metabolism, as the plantlets cannot perform photosynthesis in the culture vessel.

Gelling Agent: Agar is used to solidify the liquid medium, providing a stable surface for the explants to grow on.

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Plant Growth Regulators (PGRs): This is the most critical component. A precise ratio of plant hormones, primarily auxins (e.g., NAA) and cytokinins (e.g., BAP), dictates the outcome. The initial medium often has a balance of these hormones to induce either a mass of undifferentiated cells called a callus or to directly form shoots.

Shoot Multiplication

Once the explants have established and begun to grow, they are moved to a fresh medium with a different hormone balance that promotes shoot proliferation. A high concentration of cytokinins is used to stimulate the development of multiple shoots from a single explants. Each of these newly formed shoots can be separated and transferred to a new culture vessel, leading to an exponential increase in the number of plantlets. This is the multiplication stage where the technique's commercial value becomes apparent, as thousands of identical shoots can be generated from just one original piece of tissue.

Key Advantages and Applications in Onion Cultivation

The systematic process of tissue culture offers a suite of advantages that address some of the most pressing challenges in conventional onion cultivation. Its benefits span from improving crop quality to accelerating breeding programs and ensuring year-round supply.

Production of Disease-Free Stock: One of the most significant benefits of tissue culture is the ability to produce pathogen-free planting material. Onions are susceptible to a wide range of debilitating diseases, including those caused by viruses and fungi (e.g., Fusarium basal rot). By initiating the culture from healthy meristematic tissue in a sterile environment, the resulting plantlets are guaranteed to be free from these pathogens. This leads to healthier crops, reduces the need for costly and harmful fungicides, and ultimately results in higher yields and better product quality.

Rapid and Large-Scale Propagation: Traditional methods of onion propagation, such as planting sets or seeds, are relatively slow and labor-intensive. In contrast, tissue culture allows for the mass multiplication of a single elite plant in a short period. From just one superior onion bulb, thousands of genetically identical clones can be produced within a few months. This rapid scaling is invaluable for quickly distributing a new, high-performing variety to a wide market or for restocking a region after a crop failure.

Genetic Uniformity: Unlike hybrid seed production, where some genetic variation can occur, tissue culture ensures complete genetic fidelity. Every single plantlet is an exact clone of the parent plant. This genetic uniformity guarantees that desirable traits, such as uniform bulb size, color, flavor, or disease resistance, are consistently expressed across the entire field. For commercial farmers, this means a predictable and high-quality harvest, which is essential for meeting market demands. This is also crucial for maintaining and multiplying male-sterile lines used in hybrid onion seed production.

Year-Round Production and Germplasm Conservation: Field cultivation of onions is seasonal and dependent on climatic conditions. Tissue culture, however, can be performed in a controlled laboratory environment throughout the year, independent of the seasons. This enables a continuous supply of high-quality onion plantlets, allowing farmers to plant at any time, which can improve cropping cycles and profitability. Additionally, the technique is a powerful tool for germplasm conservation. It provides a secure way to preserve rare, wild, or valuable onion varieties in a sterile environment, protecting them from pests, diseases, and environmental changes.

Acclimatization, Challenges and Future Directions

While tissue culture offers immense benefits, the journey from lab to field is not without its challenges. The final stage of the process, acclimatization, is often the most critical and challenging, and the technology itself has limitations that researchers are working to overcome.

The Crucial Step of Acclimatization (Hardening): Plantlets grown in a sterile, humid environment are extremely delicate and sensitive to change. They lack a protective waxy cuticle, and their stomata (pores for gas exchange) do not function properly. The acclimatization or "hardening" phase is a gradual process where the plantlets are transitioned from the lab to a greenhouse environment. They are transferred to a sterile soil mix and exposed to increasing levels of light and decreasing humidity over a period of weeks. This allows them to develop a functional root system, a waxy cuticle, and robust stomata, enabling them to survive and thrive in the field. A failure in this stage can lead to significant plant losses.

Challenges and Limitations of the Technology

Despite its power, tissue culture is not a perfect solution for all scenarios.

High Costs and Technical Expertise: Setting up a tissue culture laboratory is capital-intensive, requiring specialized equipment and infrastructure. The process also demands a high level of technical skill and meticulous attention to detail from trained personnel.

Risk of Contamination: Despite stringent sterilization protocols, the risk of microbial contamination remains a constant threat. A single contaminated vessel can lead to the loss of an entire batch of plantlets.

Somaclonal Variation: While the goal is genetic uniformity, sometimes, genetic changes (called somaclonal variation) can occur during the prolonged cloning process. These variations can lead to undesirable traits in the final plants. Researchers are working to optimize protocols to minimize this risk.

Future Directions in Onion Tissue Culture

The field is constantly evolving to make the technology more accessible and efficient. Future research and development are focused on:

Automation: Developing automated bioreactor systems for large-scale liquid culture can significantly reduce manual labor and production costs.

Low-Cost Media: Exploring and utilizing less expensive alternatives to the standard MS medium to make the technology more economically viable for small-scale operations.

Cryopreservation: Using tissue culture in combination with cryopreservation (freezing plant tissue at very low temperatures) for long-term storage of valuable onion germplasm.

Onion tissue culture is a sophisticated biotechnological tool that has moved from the research lab to a commercial reality. It offers a solution to many of the challenges facing onion cultivation, from disease and pests to a lack of uniform, high-quality planting material. The enduring legacy of this technology is its ability to ensure a more sustainable, profitable, and secure future for this essential crop.

Root System Architecture (RSA) Breeding

Nivetha A. L., Vengatesh M. and Shridevi S.

Root system architecture (RSA) breeding is a critical and increasingly important area in crop science, especially in the context of climate change, water scarcity, and the need for more nutrient-efficient agriculture. While the "Green Revolution" largely focused on above-ground traits for yield, the "hidden half" of the plant - the roots - holds immense untapped potential for improving crop resilience and productivity.

What is Root System Architecture (RSA)?

Root System Architecture (RSA) refers to the spatial configuration and three-dimensional arrangement of a plant's root system within the soil. It describes how roots grow, branch, spread, and penetrate the soil profile over time. RSA is a complex trait determined by both the plant's genetics and its interaction with the surrounding environment (soil type, water availability, nutrient distribution, temperature, pH, and microbial communities). Key components and parameters defining RSA include:

Root Type

Taproot system: A single, dominant main root (taproot) that grows vertically downwards, with smaller lateral roots branching off (e.g., carrots, many dicots, some cereals like wheat).

Fibrous root system: A network of many slender, branching roots of similar size, often originating from the stem base (e.g., grasses, most cereals like rice, maize).

Adventitious roots: Roots that arise from non-root tissues (e.g., stems, leaves), such as nodal roots in maize or brace roots.

Root Depth and Angle: How deep the roots penetrate and the angle at which lateral roots emerge from the main axis.

Root Length and Branching Density: The total length of the root system and the number of lateral roots per unit length of the main root.

Root Diameter: The thickness of different root types (fine roots vs. thick roots).

Root Hairs: Microscopic extensions on epidermal cells that significantly increase the root surface area for absorption.

Root Biomass: The total dry weight of the root system.

Root Distribution: The spatial spread of roots in different soil layers.

Longevity of roots: How long individual roots or the entire system remains active.

RSA is highly plastic, meaning it can adjust its form in response to environmental cues (e.g., growing deeper in response to drought, or branching

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more densely in nutrient-rich patches).

Why is Root System Architecture Important for Crop Productivity?

Roots are the plant's interface with the soil, performing crucial functions for growth, survival, and productivity. An optimized RSA is vital because:

Water Acquisition: Roots are the primary organs for water uptake. A deeper root system (e.g., a strong taproot or deeply penetrating fibrous roots) allows plants to access water from deeper soil profiles, crucial for drought tolerance. A denser root system in the topsoil can capture sporadic rainfall more effectively.

Nutrient Uptake

Mobile Nutrients (e.g., Nitrate, Sulfate, Boron): These nutrients move with soil water. A deeper root system with greater total length can effectively intercept these nutrients as water moves through the soil.

Immobile Nutrients (e.g., Phosphorus, Potassium, Zinc): These nutrients have low mobility in the soil. A denser, more branched root system with a larger surface area (including root hairs) in the upper soil layers can explore a greater volume of soil to acquire these nutrients.

Anchoring and Stability: A robust root system provides mechanical support, anchoring the plant firmly in the soil, which is essential for standability, especially for tall crops like maize and sugarcane, and for preventing lodging (falling over).

Soil Health and Carbon Sequestration: Roots release exudates that influence soil microbial communities, aggregate soil particles, and improve soil structure. Deeper and more extensive root systems can significantly contribute to soil organic carbon (SOC) sequestration, playing a role in climate change mitigation.

Stress Tolerance: Beyond drought and nutrient deficiency, specific RSA traits can confer tolerance to other abiotic stresses (e.g., aluminum toxicity, salinity, waterlogging) and biotic stresses (e.g., root diseases, nematodes) by either avoiding the stress, mitigating its effects, or fostering beneficial microbial interactions.

Symbiotic Relationships: Roots form crucial symbiotic relationships with beneficial soil micro-organisms, such as mycorrhizal fungi (enhancing phosphorus uptake) and nitrogen-fixing bacteria (in legumes). RSA can influence the extent and effectiveness of these symbioses.

Objectives of Root System Architecture Breeding

The primary objective of RSA breeding is to design and develop crop varieties with “ideal root system ideotypes”" that are specifically adapted to target environments and agricultural practices. This means moving beyond maximizing above-ground yield under optimal conditions to optimizing below-ground performance under suboptimal or stress conditions. Specific objectives include:

Improved Drought Tolerance: Breeding for deeper rooting (e.g., steeper root growth angles), increased root length density at depth, and enhanced root hydraulic conductivity to access deeper soil moisture and maintain water uptake under water deficit.

Enhanced Nutrient Use Efficiency (NUE and PUE)

For mobile nutrients (e.g., N): Breeding for deeper, more extensive root systems to capture leached nutrients.

For immobile nutrients (e.g., P): Breeding for denser lateral branching, longer root hairs, and increased root exudation of organic acids (to solubilize P) in the topsoil.

Tolerance to Specific Soil Constraints

Acidic Soils: Breeding for roots that can tolerate aluminum toxicity, often by breeding for varieties that exude organic acids that chelate aluminum.

Saline Soils: Developing roots with better ability to exclude salt or tolerate higher salt concentrations.

Compacted Soils: Breeding for roots that can penetrate compacted layers.

Improved Anchorage: For crops prone to lodging, breeding for stronger adventitious or crown roots that provide better stability.

Reduced Resource Competition (for Intercropping / Agroforestry): Designing root systems that explore different soil strata to minimize competition between intercropped species for water and nutrients.

Enhanced Carbon Sequestration: Selecting for root ideotypes that promote greater biomass below ground and deeper carbon deposition.

Challenges in RSA Breeding

Despite its importance, RSA breeding is inherently challenging compared to breeding for above-ground traits:

Hidden Nature: Roots are hidden underground, making direct observation and phenotyping (measuring root traits) difficult, time-consuming, and destructive.

Phenotyping Bottleneck: High-throughput, non-destructive root phenotyping in field conditions remains a major bottleneck. Traditional methods involve arduous excavation and washing, while advanced techniques are often expensive or limited to controlled environments.

Environmental Plasticity: Root architecture is highly influenced by the environment. A root system that performs well in one soil type or moisture regime might not in another, complicating the identification of stable genetic traits.

Genetic Complexity: Most desirable RSA traits are quantitative (controlled by many genes), making their genetic dissection and manipulation challenging.

Trade-offs: Improving one root trait might come at the expense of another. For instance, developing a deeper root system might reduce lateral root development in the topsoil, potentially impacting shallow nutrient uptake.

Genotype-by-Environment Interaction (GxE): The performance of a specific root ideotype can vary significantly across different environments, requiring extensive testing.

Breeding Methods and Technologies for RSA

Overcoming the challenges of RSA breeding requires a multi-pronged approach, combining traditional methods with cutting-edge technologies.

Phenotyping Technologies (Measuring the

"Hidden Half")

Significant advancements in phenotyping are crucial:

Traditional Methods

Shovelomics: Digging up root crowns (especially in cereals) and visually assessing root angles, number, and depth. Relatively high-throughput but destructive.

Rhizotrons: Growth chambers with transparent walls (e.g., glass or plexiglass) allowing non-destructive, real-time observation and imaging of root growth. Limited by space and unnatural soil conditions.

Core Sampling: Taking soil cores to analyze root density at different depths. Destructive and laborious.

Advanced Imaging and Sensing

- ✓ Minirhizotrons
- ✓ X-ray Computed Tomography (CT) / Magnetic Resonance Imaging (MRI)
- ✓ Electrical Resistivity Tomography (ERT)
- ✓ Ground Penetrating Radar (GPR)
- ✓ Digital Image Analysis
- ✓ Drone/Remote Sensing (Indirect)

Breeding Strategies

Conventional Breeding and Selection: Identifying germplasm with desirable root traits (e.g., landraces, wild relatives) and incorporating them into breeding programs through crossing and repeated selection. Selection can be done in stressed environments (e.g., drought-prone fields) where genotypes with beneficial RSA will show superior performance.

Marker-Assisted Selection (MAS): Once quantitative trait loci (QTLs) or specific genes associated with desirable RSA traits (e.g., root angle, root length, root hair density) are identified, DNA markers linked to these traits can be used for efficient selection at early seedling stages. This bypasses the need for laborious root phenotyping. Examples: "DRO1" gene in rice for deeper rooting, improving drought tolerance.

Genomic Selection (GS): Utilizes genome-wide marker data to predict the breeding value of individuals for complex RSA traits. This is particularly powerful for traits influenced by many small-effect genes.

Genetic Engineering: Introducing or modifying genes directly to engineer specific RSA traits. For instance, overexpressing genes that promote lateral root branching or root hair development.This allows for the introduction of traits that may not exist within the available germplasm.

Genome Editing (CRISPR-Cas9): Offers unprecedented precision to target and modify specific genes involved in root development pathways. This can be used to fine-tune root growth angles, alter root hair formation, or enhance beneficial microbial interactions without introducing foreign DNA. Potentially faster regulatory approval due to the absence of foreign DNA.

Rootstock Breeding (for Grafted Crops): For crops like fruit trees and some vegetables (e.g., tomatoes, potatoes, solanaceous crops), the root system (rootstock) can be bred separately and then grafted with a scion (above-ground part) to confer stress tolerance, disease resistance, or improved nutrient uptake through the root system. This allows for targeted root improvement without altering the fruit/vegetable quality of the scion.

Modeling and Simulation: Computational models (e.g., SimRoot) can simulate root growth under different conditions and predict the optimal RSA for specific environments. These models can guide breeding targets and help prioritize which root traits to focus on.

Conclusion

Root system architecture breeding represents the "next frontier" in crop improvement. By moving beyond a singular focus on above-ground yield and delving into the intricacies of the plant's hidden half, breeders can unlock unprecedented levels of resilience to environmental stresses and efficiency in resource utilization. While challenging due to the below-ground nature of roots and the complexity of their genetics, advancements in phenotyping, genomics, and gene editing are rapidly transforming this field. In countries like India, where agriculture is particularly vulnerable to climate change and resource depletion, investing in RSA breeding is not just an academic pursuit but a strategic imperative for ensuring food security, environmental sustainability, and the long-term viability of agriculture.

The Role of Crops in Mitigating Coastal Salinity

Shridevi S., Vengatesh M. and Nivetha A. L.

Crops play a vital role in conserving coastal salinity by absorbing excess salt from the soil and preventing its upward movement. These plants, known as halophytes, are naturally adapted to saline conditions. By cultivating them, we can reclaim salt-affected land, prevent further soil degradation, and protect the livelihoods of coastal communities.

The Mechanisms of Salinity Conservation by Crops

Coastal areas are highly vulnerable to salinity, which is a major threat to agricultural productivity and environmental health. The primary source of this salinity is saltwater intrusion, where seawater infiltrates freshwater aquifers and agricultural lands. Traditional crops cannot tolerate high salt concentrations and fail, leading to desertification and economic loss. Halophytic crops, however, possess unique biological mechanisms to not only survive in saline conditions but also actively mitigate them.

Phyto-remediation: The Active Removal of Salt

The most important role of these crops is phyto-remediation, a process where plants are used to clean contaminated soil. Halophytes have specialized cellular mechanisms to absorb salt from the soil through their roots. They then transport this salt and sequester it in specific parts of the plant, such as the leaves, stems, or vacuoles within their cells. Some halophytes even possess specialized salt glands on their leaves that excrete excess salt onto the leaf surface. When the plant is harvested or its leaves naturally senesce and fall, the salt is effectively removed from the soil, leading to a gradual but significant reduction in soil salinity over time.

Preventing Salt Capillary Rise

In many coastal regions, a high water table is a major contributor to soil salinity. Saltwater from the ground rises to the soil surface through capillary action, where it evaporates, leaving behind a crust of salt. The deep and extensive root systems of many halophytic crops and trees, such as Casuarina, act as a natural pump. By drawing water from the ground, they lower the water table and interrupt this capillary movement, effectively preventing salt from accumulating in the topsoil. This is a crucial mechanism for long-term soil health.

Key Halophytic and Salt-Tolerant Crops for Coastal Conservation

The selection of appropriate crops is critical for the success of any coastal salinity conservation project. The ideal crops are not only effective at soil

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reclamation but also have commercial value, providing a financial incentive for farmers to adopt them.

Salicornia (Sea Asparagus): A High-Value Halophyte

Salicornia is a highly salt-tolerant succulent that is gaining popularity in gourmet markets worldwide. It can grow in extremely saline conditions, even on land irrigated with seawater. It is a prime example of a crop that directly removes salt from the soil. Its commercial value as a fresh vegetable, its use in salads, and its potential as a source of cooking oil make it a viable and profitable choice for farmers in coastal areas.

Quinoa: A Nutrient-Rich and Salt-Tolerant Grain

While not a true halophyte, quinoa is remarkably salt-tolerant and can produce a good yield in mildly to moderately saline soils where traditional cereals like wheat or rice would fail. Quinoa is a dual-purpose crop that serves both as a soil conservation agent and a nutritious food source. Its high protein content and growing market demand make it a valuable crop for promoting food security in saline-affected regions.

Casuarina (She-oak): The Coastal Protector

Casuarina trees are a staple in coastal areas for their role as windbreaks and for stabilizing sandy soils. Their deep root systems are not only effective at lowering the water table but also in binding the soil to prevent erosion from wind and water. The trees are highly tolerant of saline conditions and provide a source of firewood, poles, and other non-timber products, contributing to the local economy.

The Economic and Environmental Benefits of Cultivation

The cultivation of salt-tolerant crops is more than just an ecological endeavor; it is a vital strategy for rural economic development and environmental sustainability in coastal regions.

Economic Rejuvenation of Coastal Communities: For centuries, coastal communities whose lands were rendered unproductive by salinity have faced severe economic hardship. By introducing commercially viable salt-tolerant crops, these communities can reclaim their lands and livelihoods. The ability to grow and sell crops like Salicornia, which commands a premium price, or Quinoa, which has a stable global market, can turn barren land into a source of sustainable income. This reduces poverty and migration from coastal areas.

Environmental Sustainability and Biodiversity

The cultivation of these specialized crops contributes significantly to environmental sustain-ability.

Reversing Soil Degradation: By actively removing salt and improving soil structure, these crops help to reverse the process of salinization. This reclaims land for future agricultural use and restores ecological balance.

Habitat Creation: The establishment of vegetation in previously barren, salt-affected areas provides new habitats for local flora and fauna. This helps to restore local biodiversity and strengthens the coastal ecosystem.

Reduced Chemical Input: Many salt-tolerant crops have evolved natural resistance to local pests and diseases, reducing the need for chemical fertilizers and pesticides. This contributes to a healthier environment and reduces farming costs.

Global Case Studies and Future Potential

The successful use of crops for coastal salinity conservation is not just a theoretical concept; it has been proven in various projects around the world. These case studies highlight the immense potential of this approach.

The Israeli Negev Desert: Israeli scientists have pioneered the use of saltwater for irrigation, cultivating halophytes like Salicornia and quinoa in the arid Negev Desert. This has transformed a previously non-agricultural region into a productive one and serves as a model for other arid, saline-affected areas globally.

Coastal Regions in India: In India, research institutions and government bodies are working with farmers in states like Gujarat and Tamil Nadu to promote the cultivation of salt-tolerant crops. Projects focus on identifying local landraces of millets and other crops that can withstand saline conditions, thereby empowering local farmers with sustainable agricultural pratices.

Future Potential and Research

The field of crop-based salinity conservation is a growing area of research. Scientists are working on:

Genetic Engineering: Developing new crop varieties that are even more tolerant to salinity through genetic engineering and selective breeding.

Integrated Farming Systems: Creating integrated farming systems that combine aquaculture (raising fish in saline water) with halophyte cultivation, where the waste from the fish provides nutrients for the plants.

Bioremediation: Exploring the use of specific plant-microbe interactions to enhance the salt-absorbing capacity of crops.

Conclusion: The Integral Role of Crops in a Sustainable Coastal Future: The role of crops in conserving coastal salinity is an integral part of a sustainable coastal management strategy. The traditional approach of combating salinity with engineering solutions has often proven costly and unsustainable. The biological approach, centered on the cultivation of specialized crops, offers an economically viable, environmentally friendly and community-empower-ing alternative. By harnessing the power of halophytes, we can:

Reclaim Barren Land: Transform salt-affected wastelands into productive agricultural fields.

Empower Communities: Provide a new source of income and livelihoods for coastal communities.

Protect the Environment: Restore soil health, prevent erosion, and enhance biodiversity.

In essence, these crops are not just a tool for conservation; they are a key to building a resilient and prosperous future for the world's coastal regions. They represent a fundamental shift in agricultural thinking from fighting against nature to working with it to achieve sustainable development.

Role of Women in Upcoming Agriculture

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Agriculture is the backbone of our country but the latest changes in it is led by climate variations, innovative machines, apps and technology opened a wide challenges and opportunities. In developing nations like India, agricultural transformation in 21^{st} century encouraged women participation constituting half of the workforce. Women have long been involved in agriculture, helping with planting, weeding, harvesting, and storing crops, but their contributions were often overlooked. However, their full potential is nonetheless hidden by persistent issues such institutional limits, gender bias, limited land ownership, and lack of access to financing. With an emphasis on India and developing nations, this chapter examines how women's roles in agriculture are changing and highlights their potential, challenges, and contributions to the creation of a sustainable and inclusive agricultural future.

Introduction

Women's participation in the agricultural sector at every stage, from planting and seed selection to post-harvest processing and sale, results in a substantial financial gain. Women make up over 43% of the agricultural labor force in developing nations, and even more in some states, according to the FAO. However, their contributions are sometimes overlooked and underappreciated. Globalization, climate change, technology, and changing socioeconomic dynamics are all reshaping agriculture's future, bringing with them opportunities and challenges, with a particular emphasis on the role of women in Agriculture and allied sectors. Adapting gender equity and acknowledging women as innovators, entrepreneurs, and leaders in the agricultural transformation process is crucial for ensuring inclusive growth and food security. This article expresses the various roles that women play in agriculture, especially in developing nations, and offers ways to increase female involvement.

Evolving Roles of Women in Modern Agriculture : In many developing countries, especially India, women's empowerment rose as their roles shifted from labor-intensive to more strategic and knowledge-driven. The majority of women's roles are limited to being the backbone of food security in the home and community. Their duties go well beyond the kitchen; they actively cultivate food and cash crops and support the country's agricultural production at the same time. In addition to growing commercial crops that boost rural economies, women are essential in producing subsistence foods

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that support their families. Through their diverse engagement, they improve the agricultural landscape as a whole in addition to guaranteeing steady food availability. Agriculture is changing due to mechanization, digital technologies, biotechnology, and market integration, and more women are getting involved in these new fields. The feminization of agriculture is also seen in India, where women are now the main farmers and decision-makers in rural farms due to male migration to urban areas. Participatory breeding initiatives, organic farming, integrated pest management, and seed production all actively engage women. Additionally, they are supporting value chain growth, agribusiness management, and on-farm innovation. Self-help groups (SHGs) and Farmer Producer Organizations (FPOs) run by women are essential for increasing income, expanding market access, and bolstering community resilience. One such programme is active in Tamil Nadu, with support from the Plantwise Plant clinic programme and the M.S. Swaminathan Research Foundation, women's groups have become commercially successful biopesticide producers (https://www.cabi.org/stories-of-impact/plant-clinics-boost-womens-empowerment-through-biopesticide-production-groups/). Their products are now supplied to local plant clinics and farming communities, demonstrating the power of grassroots innovation in agricultural health.

Women and Climate-Smart Agriculture: Climate change poses a severe danger to agricultural production, rural livelihoods, and food security. Because they are often responsible for the preservation of natural resources including as soil, water, and biodiversity, women are leading adaptation and mitigation efforts. Climate- smart agriculture (CSA), which integrates resilience-building, environmental practices, and greenhouse gas reduction, offers multiple opportunities for women's empowerment. Women are adopting practices including crop diversification, conservation agriculture, agroforestry, and organic composting to adjust to the changing environment. In Africa and India, communal seed banks run by women have increased genetic variety and resistance to pests and drought. Furthermore, women's knowledge of regional ecosystems and traditional farming practices is essential to developing adaptable solutions that are both socially and environmentally acceptable. However, there are still major barriers related to gender disparities in access to climate information, financing, and extension services. Gender-responsive policies, inclusive climate advisory services, and targeted training are necessary to maximize women's participation in climate-smart transitions.

Agri-Entrepreneurship and Value Chain Participation: Innovation-driven, knowledge-intensive, and market-oriented are traits of the modern agri-food system. Women now have more opportunities to become agri-entrepreneurs and lead value chains outside of primary farming because to this shift. Women-owned companies in marketing, packaging, food processing, and agritourism are increasing employment and diversifying the rural economy. Digital platforms and e-commerce have provided women with unprecedented access to markets and direct consumer connection. Thanks to initiatives like the Mahila Kisan Sashaktikaran Pariyojana (MKSP) and NABARD's support for women FPOs, thousands of Indian women have founded microenterprises in the dairy, poultry, horticultural, and non-timber forest products sectors. Mentoring, firm growth services, and financial access remain crucial. In order to assist women in growing their agriculture ventures, digital literacy campaigns, loan guarantee schemes, and women-only incubators must be put into place.

Policy, Education, and Capacity Building: In order to increase women's involvement and leadership in agriculture's future, policy initiatives and institutional frameworks are essential. Dismantling long-standing structural inequities and closing the gender gap in the industry require gender-responsive agriculture policy, fair land reforms, and focused financial incentives. Initiatives like the National Rural Livelihood Mission (NRLM) in India and the gender mainstreaming programs run by IFAD in Africa and Asia show how inclusive policy design may greatly increase women's access to entrepreneurial opportunities, decision-making spaces and productive resources. Initiatives for capacity-building and education also have a transformative effect. Rural women's confidence is increased and their leadership potential is increased when they receive training in digital technologies, sophisticated agronomic techniques, climate-smart tactics, and financial management. In order to guarantee greater participation and more efficient information sharing, agricultural extension services must also be refocused to meet the unique needs of women farmers. This includes more female extension staff, flexible scheduling, and community-driven models.

Challenges and Barriers: Despite the tremendous contributions women have made to agriculture, a number of obstacles still stand in their way and keep them from realizing their full potential. One of the most pressing issues is the persistent disparity in land ownership; in India, for instance, women own fewer than 13% of the country's agricultural land. This limited access to property not only compromises their financial independence but also impairs their decision-making skills. Women's mobility, participation and leadership opportunities in agricultural decision- making are further limited by gender stereotypes, deeply rooted social norms, and the substantial burden of unpaid caring and household responsibilities. Access to institutional finance and financial services remains a significant barrier. Many women farmers are unable to obtain loans and adopt modern inputs, improved seeds, and advanced technologies because they lack the necessary financial skills or are unable to provide collateral. Furthermore, due to limited access to current market information, digital advancements, and agricultural extension services, the gender gap widens and their capacity to engage in evolving agri-value chains is restricted. Women are also disproportionately affected by the negative consequences of climate change because their livelihoods often rely heavily on natural resources and because socioeconomic inequities hinder their ability to adapt. To address these complicated difficulties, comprehensive and coordinated therapies are required. Women's land rights must be strengthened through legal reforms, gender-sensitive budgeting, targeted capacity-building and extension initiatives, improved access to credit and technology, and robust social protection systems in order to close the gender gap and enable women to play a significant role in agricultural transformation.

Future Prospects and the Way Forward: Future agricultural practices in underdeveloped countries will be characterized by innovation, sustainability, and inclusivity, and women will be crucial to this change. Digital agriculture, artificial intelligence, genomics, vertical farming, and the bioeconomy are all transforming agri-food systems. If given the proper instruction and institutional support, women may lead these technical frontiers. Through public-private partnerships, gender- responsive innovation platforms, and mentorship networks, women's participation in research, entrepreneurship, and leadership roles can be expedited. Supporting female role models, promoting women in STEM fields, and incorporating gender equity into national agriculture goals are all necessary for a more inclusive future. Ultimately, achieving the Sustainable Development Goals (SDGs), particularly SDG 2 (Zero Hunger), SDG 5 (Gender Equality), and SDG 13 (Climate Action), requires women's empowerment and is not only a social justice issue.

Conclusion

In the 21st century, women are leading the way in agricultural change, especially in developing countries like India, where they play a variety of roles as farmers, innovators, entrepreneurs, educators, and policymakers. In addition to being essential to agricultural expansion, their active involvement serves as a catalyst for tackling some of the most important global issues, such as promoting biodiversity, improving climate resilience, guaranteeing food and nutritional security, and advancing sustainable rural development.

The tide is slowly shifting in spite of enduring obstacles such unequal access to land, credit, education, and decision-making platforms. New opportunities for women's empowerment and leadership are being created by progressive legislation, focused capacity- building initiatives, technology advancements, institutional reforms, and growing awareness of their priceless contributions. It is impossible to foresee agriculture's future without women at its core. An inclusive, gender- responsive, and progressive agricultural system that recognizes women as visionaries, innovators, and change agents in addition to their contributions is essential to being really modern and sustainable. In addition to revolutionizing agriculture, providing women with equal opportunities, resources, and knowledge would improve entire communities, boost economies, and create a more resilient and equitable world. Essentially, women must be seen as equal participants and leaders in the next chapter of agriculture, helping to shape policies, direct inventions, and care for the soil that supports humankind. Their leadership is strategically necessary to ensure future generations have a sustainable, climate-resilient, and food-secure future, and it goes beyond issues of fairness or equality.

References

FAO (2022). The State of Food and Agriculture 2022. Rome: Food and Agriculture Organization.

Gautam, U.S., Singh, A. and Singh, S. R. K. (2012). Participatory approach of women in agriculture: Vision 2025. *Indian Research Journal of Extension Education*, 1: 38-42.

Government of India (2021). Agriculture Census 2015-16. Ministry of Agriculture and Farmers' Welfare.

IFAD (2020). Gender equality and women's empowerment in rural development. Rome: International Fund for Agricultural Development.

NITI Aayog (2022). Women in agriculture: Challenges and opportunities. Government of India.

UN Women (2021). Progress of the World's Women 2021-2022. New York.

United Nations. World Bank (2023). Gender and Agriculture in South Asia. Washington, DC: World Bank.

Broad Bean: A Cool Season Legume for Health and Sustainability

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Introduction

Broad bean (*Vicia faba* L.) belongs to the family Leguminosae (Fabaceae) and has a chromosome number of 2n = 24. It is an annual legume crop considered to have originated in the Mediterranean region. Broad bean holds the first place among pulse crops in Algeria due to its high nutritional value. It is a cross-pollinated crop with a natural outcrossing rate ranging from 19-49%, which is influenced by various biotic and abiotic factors. Broad bean is a cool-season crop known by several vernacular names, including *faba bean, fava bean, horse bean, tick bean, Windsor bean, baby kurmouje, faverira, full masri, yeshil bakla,* and *feve*. It is regarded as one of the oldest cultivated crops in the world and ranks third among feed grain legumes after pea (*Pisum sativum*) and soybean (*Glycine max*). In India, broad bean cultivation is limited, and hence, it is classified as a minor crop. The green pods are primarily used as a vegetable, while the dry cotyledons serve as a rich source of protein. Broad beans are notable for containing L-DOPA (levodopa), a biochemical precursor of dopamine, making them valuable for both nutritional and pharmaceutical uses. Furthermore, the crop serves as an excellent green manure, owing to its high nitrogen-fixing potential and tolerance to biotic and abiotic stresses. Despite its significance as a major food crop in Africa, India's production remains comparatively low.

Taxonomy

Kingdom: Plantae

Clade: Tracheophytes

Clade: Angiosperms

Clade: Eudicots

Clade: Rosids

Order: Fabales

Family: Fabaceae (Pea and bean family)

Subfamily: Faboideae

Genus*: Vicia*

Species*: Vicia faba* L.

Botanical description: *Vicia faba* L. is an annual legume crop that grows erectly up to 0.5-1.8 m in height. The stem is stout, firm, and square in cross-section. The leaves are pinnately compound, consisting of 2-7 leaflets with a greyish-green to glaucous (waxy) appearance, and notably, the plant lacks tendrils. The flowers are borne in axillary clusters on short peduncles and are white, pink, or crimson in colour, often marked with distinct black spots on the wings. The pods are broad and leathery, initially green but turning dark blackish-brown upon maturity. Pods typically measure 15-25 cm in length and contain 3-8 seeds.

Climate and soil required: Broad bean is an important winter season crop that is well adapted to

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Nutrients

Phytochemicals	Value/100 g (unit)	Phytochemicals	Value/100 g (unit)
Carbohydrate, by difference	133.33 g	Thiamine	0.029 mg
Energy	71 kcal	Water	81.17 g
Total lipid (fat)	0.29 g	Vitamin C, total ascorbic acid	7.3 g
Protein	4.07 g	Riboflavin	0.43 mg
Fiber, total dietary	3.6 g	Vitamin B_6	0.062 mg
Calcium	28 mg	Folate, DFE	16 µg
Iron	1.61 mg	Niacin	0.532 mg
Magnesium	34 mg	Vitamin B_{12}	0.00 µg
Potassium	285 mg	Vitamin A, IU	150 IU
Phosphorous	71 mg	Vitamin A, RAE	8 µg
Zinc	0.64 mg	Vitamin D	0 IU
Sodium	252 mg	Vitamin D (D_2+D_3)	0.0 µg
Fatty acids, total saturated	0.066 g		

cool climatic conditions. It is a cross-pollinated legume capable of thriving in well-drained, fertile soils rich in organic matter. The optimum temperature for its growth and development ranges between 15-25°C. It grows best in loamy soils with a pH range of 6.5-7.5. Adequate sunlight exposure of at least 6-8 hours day^{-1} is essential for proper vegetative growth, flowering, and pod formation.

Sowing: Seeds are directly sown in the field at a depth of about 5 cm. A special intercultural operation known as nipping is performed during the flowering stage to control black fly infestation and promote better branching. Well-decomposed farmyard manure (FYM) is incorporated into the soil as a basal application during ploughing to enhance soil fertility. The seed rate varies depending on the growth habit of the variety: 50-90 kg ha^{-1} for bush-type varieties and 25-30 kg ha^{-1} for pole-type varieties. The recommended spacing is 45-60 cm for bush types, while pole-type varieties are planted at a wider spacing of 1.0 m hill^{-1} to accommodate vigorous growth and staking requirements.

Harvest and yield: Broad bean is harvested at the young and tender stage, approximately 50-60 days after sowing, when grown for vegetable purposes. For seed production, the pods are allowed to mature and dry completely on the plant, after which the dry pods are collected, and the seeds are separated by threshing. The average yield of broad bean ranges from 70-100 q ha^{-1} (7-10 t ha^{-1}) of green pods, depending on the variety, management practices, and environmental conditions.

Uses

- ✓ It is used as cover crop to protect soil erosion.
- ✓ It can also be grown as green manure crop to improve the soil fertility.
- ✓ It is used as forage crop to feed livestock.
- ✓ It is the crop with high nutritive value.
- ✓ It's consumed as salad or cooked vegetables.

Conclusion

Broad bean is a rich source of protein and serves as a valuable component of a balanced diet. It has the ability to fix a higher amount of atmospheric nitrogen compared to many other legume crops, thereby improving soil fertility and reducing the need for synthetic nitrogen fertilizers. Hence, farmers can benefit economically by cultivating broad bean, as it not only provides income generation but also contributes to nutritional security and sustainable agriculture.

References

Free, J. B. (1966). The pollination requirements of broad beans and field beans (*Vicia faba*). *The Journal of Agricultural Science*, 66(3): 395-397.

Pasqualone, A., Abdallah, A. and Summo, C. (2020). Symbolic meaning and use of broad beans in traditional foods of the Mediterranean Basin and the Middle East. *Journal of Ethnic Foods*, 7(1): 39.

L'Hocine, L., Martineau-Côté, D., Achouri, A., Wanasundara, J. P. and Loku Hetti Arachchige, G. W. (2020). Broad bean (faba bean). In Pulses: processing and product development (pp. 27-54). Cham: Springer International Publishing.

Revolutionizing Crop Protection with Artificial Intelligence

Shail Bala

Abstract

Across the world, farmers face a silent enemy, plant diseases that quietly steal yields and threaten food security. Early and accurate detection is essential for sustainable crop management. Advances in Artificial Intelligence (AI) and Machine Learning (ML) now enable automated disease identification using tools like smartphones, drones and field sensors. AI models such as Convolutional Neural Networks (CNNs) and You Only Look Once (YOLO) can evaluate leaf images to detect infections and classify diseases quickly and accurately. These technologies support timely decision-making, reduce pesticide misuse and enhance productivity. Although challenges like limited datasets and environmental variability remain, integrating AI with remote sensing and Internet of Things (IoT) has strong potential to enhance precision and sustainable agriculture.

Introduction

Plant diseases are among the most serious challenges to global food production. Each year, a large share of crop yield is lost due to fungal, bacterial, and viral infections. For farmers, early and precise disease detection is essential to protect crops and ensure better harvests. Conventionally, this has been done through visual inspection by farmers or experts a process that is time-consuming, laborious and often prone to mistakes as numerous diseases exhibit overlapping symptoms (Barbedo, 2016). Today, the rise of Artificial Intelligence (AI) and Machine Learning (ML) has opened a new chapter in agriculture. These technologies are enabling automated, image-based plant disease detection using simple tools such as smartphones, drones and field sensors. The result is faster, more reliable and affordable solutions for identifying crop diseases, enabling farmers to take smarter actions at the right time (Kalaivani *et al.*, 2025).

How AI and machine learning help in detecting plant diseases

Machine Learning, a subfield of AI, allows computers to learn from data and make predictions without explicit programming. In agriculture, ML models are trained on thousands of labeled images of healthy and diseased plant leaves. After training, these models are able to recognize and classify diseases in new, unseen images with remarkable accuracy.

The general workflow includes the following steps:

Data collection: Images of healthy and Pictures of diseased leaves are collected through smartphones, digital cameras or drones.

Image preprocessing: The collected images are cleaned, resized, and enhanced to improve quality.

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Augmentation approaches, including rotation, scaling and flipping are often used to make the model more robust.

Feature extraction: The system learns visual features such as colour, shape and texture that help distinguish diseased regions from healthy tissue.

Model training and validation: Deep learning networks especially Convolutional Neural Networks (CNNs) are trained to identify disease types based on these features.

Prediction: Once trained, the model can predict whether a new image is healthy or affected by a specific disease.

For instance, when a farmer uploads a photo of a groundnut or mungbean leaf, the AI model can immediately identify whether it shows signs of rust, leaf spot or mosaic virus, all within seconds.

Popular AI and ML models used in agriculture

CNNs: CNNs are commonly used deep learning models for image-based disease detection. Architectures such as VGG16, ResNet50, Inception V3 and DenseNet121 have achieved excellent accuracy. These models automatically learn to detect visual differences that are often invisible to the human eye (Ayyappan *et al.*, 2025).

YOLO: The YOLO family of models (v5, v8, v10, v11) is designed for real-time object detection. They not only classify the disease but also highlight the affected areas using bounding boxes. This helps in monitoring disease spread across fields quickly (Onler and Koycu, 2024).

Traditional machine learning models: Algorithms like Support Vector Machines (SVM) and Random Forests are still useful for smaller datasets or simpler classification problems where deep learning may not be required (Hatuwal *et al*., 2020).

Transfer learning: Instead of starting from scratch, scientists use pre-trained models, originally trained on large datasets like ImageNet and fine-tune them for specific crops or diseases. This saves time and boosts accuracy, even with a small amount of agricultural data (Hossen *et al*., 2025).

Applications of AI in modern agriculture

Field monitoring with drones: Drones equipped with high-resolution cameras can capture large-scale images of crop fields. AI models analyze these images to detect disease hotspots, allowing farmers to apply pesticides or fertilizers only where needed.

Mobile based disease diagnosis: AI-powered smartphone apps allow farmers to instantly identify plant diseases by simply taking a photo. This reduces the need for expert consultation and speeds up decision-making in the field.

Precision agriculture: By combining AI with GPS and sensor data, farmers can optimize the use of resources such as water, fertilizer and pesticides. This targeted approach reduces costs, minimizes waste and supports sustainable farming.

Research and crop breeding: Plant pathologists use AI to measure disease severity and identify resistant genotypes. This accelerates breeding programs aimed at developing disease-tolerant varieties.

Benefits of AI-based plant disease detection

High Accuracy: Advanced AI models can detect and classify diseases with over 95% accuracy.

Early Detection: Identifies symptoms in the early stages before visible damage occurs.

Cost-Effective: Reduces dependence on laboratory testing and expert visits.

Scalable: Works effectively across different crops, regions and scales.

Self-Improving: Models continue to improve as more data is collected over time.

Challenges and future prospects

Although AI-based systems show great promise, a few challenges still limit widespread adoption:

Limited data: Many developing regions lack large, high-quality, labeled image datasets for local crops.

Environmental factors: Changes in lighting, leaf angle, and background can affect prediction accuracy.

Generalization issues: Models trained on a single crop might not perform as well on other crop types or in different regions.

Awareness and training: Farmers need more exposure to digital tools and training to use them effectively.

In the coming years, the integration of AI with IoT and remote sensing will make crop monitoring even more efficient. Combining real-time data from drones, satellites, and field sensors will help build a complete view of crop health. With cloud computing and mobile-based AI tools, even those farming in remote locations can gain access to these technologies, improving productivity and sustainability.

Conclusion

Artificial Intelligence and Machine Learning are transforming plant disease detection from a manual, reactive approach into an intelligent, proactive system. These tools empower farmers to act early, reduce crop losses and make agriculture more efficient and sustainable. As technology becomes more accessible and affordable, AI-driven disease detection will play a central role in achieving smart farming and global food security ensuring healthier crops, better yields and a greener future.

References

Barbedo, J. G. A. (2016). A review on the main challenges in automatic plant disease identification based on visible range images. *Biosystems Engineering*, 144: 52-60.

Kalaivani, A., Asha, V., Sathya, J., Kumar, R., N. T., R. and Jain, R. (2025). Smart Agriculture: Federated and Centralized Ai Models for Real-Time Crop Disease Diagnosis. In *2025 6th International Conference on Inventive Research in Computing Applications (ICIRCA)* (pp. 1325-1329). IEEE.

Önler, E. and Köycü, N. D. (2024). Wheat powdery mildew detection with yolov8 object detection model. *Applied Sciences*, 14(16): 7073.

Hossen, M. I., Awrangjeb, M., Pan, S. and Mamun, A. A. (2025). Transfer learning in agriculture: a review. *Artificial Intelligence Review*, 58(4): 97.

Ayyappan, A. B., Gobinath, T., Kumar, M. and Sivaramakrishnan, A. (2025). Rice Plant Disease Detection using Convolutional Neural Networks. *Discover Artificial Intelligence*, 5(1): 50.

Hatuwal, B. K., Shakya, A. and Joshi, B. (2020). Plant Leaf Disease Recognition Using Random Forest, KNN, SVM and CNN. *Polibits*, 62: 13-19.

The Bio-pesticidal and Therapeutic Promise of *Celosia argentea* Phytochemistry

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Abstract

Celosia argentea L., commonly known as Cockscomb or Silver Cock's Comb, is a widely distributed annual herb in the family Amaranthaceae. Traditionally recognized in various cultures for its ornamental value and use as a leafy vegetable, it also holds a significant place in folk and traditional medicine across Asia and Africa for treating a range of ailments, including inflammatory conditions, diarrhoea, and eye disorders. This review synthesizes the current scientific understanding of the plant's rich phytochemistry and diverse pharmacological activities. Modern research has confirmed the presence of key bioactive compounds such as saponins, flavonoids, phenols, and betalains, which are largely responsible for its therapeutic profile. Critically, emerging studies highlight the potent antimicrobial and antifungal activities of *C. argentea* extracts against several human and plant pathogens (e.g., *Candida albicans, Aspergillus niger, Macrophomina phaseolina*). These findings position *C. argentea* as a promising, eco-friendly source for the development of natural biopesticides and fungicides, offering a sustainable alternative to synthetic agrochemicals. Furthermore, its established antioxidant, anti-inflammatory, and hepatoprotective properties underscore its value for pharmaceutical and nutraceutical applications. This paper advocates for intensified research into the in-vivo efficacy and mechanism of action of *C. argentea* extracts for integrated pest and disease management in agriculture.

Introduction

Celosia argentea L. is herbaceous plant native to tropical and subtropical regions worldwide. While often regarded as a troublesome weed in some agricultural settings, its value as an important leafy vegetable (e.g., "Lagos spinach" in West Africa) and ornamental plant is well-established. Its generic name, derived from the Greek word kelos (meaning "burned"), alludes to the flame-like appearance of its vibrant inflorescences. For centuries, *C. argentea* has been an integral component of traditional medicine systems, including Ayurveda and Traditional Chinese Medicine (TCM). Various parts of the plant especially the leaves and seeds (Semen Celosiae) have been used to treat conditions ranging from fever, diarrhoea, and wounds to more specific ailments like hypertension and "liver heat." The resurgence of interest in natural, sustainable solutions has recently *propelled C. argentea* into the spotlight for modern scientific investigation, particularly for its potential in agricultural biopesticide development.

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Phytochemical Profile and Bioactive Compounds

The diverse bioactivity *of C. argentea* is directly linked to its complex array of secondary metabolites. Extensive phytochemical screening has revealed the presence of several major classes of compounds:

Saponins: Triterpenoid saponins, such as Celosin A-G and Cristatain, are prominent, particularly in the seeds. These compounds are often linked to anti-tumor, anti-inflammatory and membrane-permeabilizing properties, the latter of which is crucial for antimicrobial action.

Flavonoids and Phenolic Compounds: High concentrations of phenolic compounds, including flavonoids like quercetin and kaempferol, are found in the leaves and aerial parts. These possess potent antioxidant and anti-inflammatory effects.

Betalains: These are water-soluble, nitrogen-containing pigments responsible for the plant's characteristic vibrant red-purple (betacyanins) and yellow-orange (betaxanthins) colors. Betalains are known for their exceptional antioxidant and free-radical scavenging capabilities.

Polysaccharides: Acidic polysaccharides, such as Celosian, isolated from the seeds, have demonstrated significant immunostimulant and anti-hepatotoxic activity.

Emerging Potential as a Natural Biopesticide

The growing global concern over the environmental impact and pathogen resistance associated with synthetic pesticides has driven the search for botanical alternatives. The inherent antimicrobial activity of *C. argentea* extracts positions it as a strong candidate for a natural biopesticide.

Antifungal Activity

Studies have consistently demonstrated that *C. argentea* extracts possess significant fungicidal potential. Specifically, the leaf and stem extracts have shown inhibitory effects against common fungal pathogens.

Mechanism of Action: The saponins and phenolic compounds are hypothesized to be the primary antifungal agents. Saponins can disrupt the cell membranes of fungi, leading to leakage of cytoplasmic content and eventual cell death. Flavonoids, on the other hand, may complex with the microbial cell wall, leading to structural and functional damage.

In-vitro Efficacy: Extracts have been effective against fungal strains such as *Candida albicans* and the plant pathogen *Macrophomina phaseolina*, which is responsible for collar rot disease in Cockscomb itself, suggesting a natural defence mechanism that can be leveraged.

Antibacterial Activity

Beyond fungi, the plant extracts particularly the ethyl acetate and methanolic extracts have exhibited bactericidal and bacteriostatic effects against a range of Gram-positive (*Staphylococcus aureus*) and Gram-negative *(Escherichia coli*) bacteria. This dual-action capability against both bacterial and fungal pathogens is a crucial feature for a broad-spectrum agricultural biopesticide.

Other Significant Pharmacological Activities

While its biopesticide potential is notable, the plant's wide-ranging traditional uses are supported by modern pharmacological data:

Antioxidant Activity: Due to its high content of phenols and betalains, *C. argentea* extracts show potent free-radical scavenging capacity, rivalling commercial standards like ascorbic acid.

Hepatoprotective Effects: The polysaccharide Celosian and triterpenoid saponins have been shown to protect the liver against chemical and immunological injuries, partly through their antioxidant and anti-inflammatory mechanisms.

Anti-inflammatory and Wound Healing: Leaf extracts, formulated as ointments, have demonstrated accelerated wound closure in animal models, promoting tissue granulation and increasing collagen content. This effect supports its traditional topical use for sores and ulcers.

Conclusion and Future Directions

Celosia argentea is a phytochemically rich plant whose potential far exceeds its common classification as a vegetable or ornamental. The scientific evidence supports its historical use in medicine, confirming significant antioxidant, anti-inflammatory, and hepatoprotective properties. Crucially for sustainable agriculture, it demonstrated broad-spectrum antimicrobial and antifungal efficacy against various pathogens strongly advocates for its development as a natural biopesticide.

Future trends

Field Trials (In-vivo Efficacy): Quantifying the dose-dependent efficacy of standardized *C. argentea* extracts against specific, economically important crop diseases under real-world agricultural conditions.

Toxicity and Safety Profiles: Thorough investigation of the safety and ecological impact of the extracts, ensuring they are non-toxic to beneficial insects, soil organisms, and human consumers.

Mechanism Elucidation: Pinpointing the exact molecular targets of its bioactive compounds against plant pathogens to optimize extraction and formulation strategies.

By bridging traditional knowledge with modern science, *Celosia argentea* holds the promise of contributing valuable, sustainable, and multi-functional solutions to both the agricultural and pharmaceutical industries.

Resilience and Risks: Indian Agricultural Exports under U.S. Trade Barriers

Manjubala M. and Jhade Sunil

Abstract

India's agricultural trade with the United States has shown consistent growth, with the U.S. ranking among India's top three export destinations. In FY 2024, agricultural exports to the U.S. reached USD 1,960.68 million, driven by key commodities such as Basmati rice, herbal and medicinal plants, natural honey, and cocoa products. The bilateral trade has expanded steadily, recording a CAGR of 13.31% since 1990. However, recent U.S. trade policies, including a universal 10% import tariff, have started to affect export performance. Despite strong overall growth in Q1 FY 2025, declines in major products indicate potential risks to long-term sustainability.

Introduction

The trade relationship between India and the United States has strengthened considerably over the years, shaped by broader geopolitical developments and economic reforms in both countries. The United States ranks among India's top export destinations, with bilateral trade currently valued at approximately USD 130 billion, of which India exports around USD 85 billion and imports about USD 45 billion.

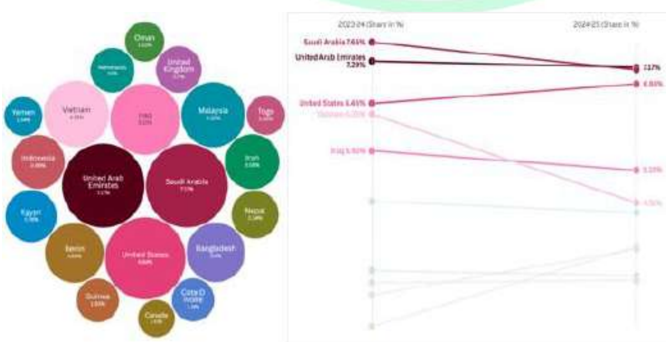

Fig. 1: Top 10 export destinations of Agricultural Products (Source: APEDA)

Major exports from India to the U.S. include smartphones and electronics, pharmaceuticals, diamonds, petrol-eum oils (excluding crude), and iron and steel products. India also holds a prominent position in global agricultural exports, with key destinations including the United Arab Emirates, Saudi Arabia, United States, Iraq, and Vietnam.

Key Agricultural Exports to the United States

The United States has consistently ranked third among India's top five export destinations over the past three years. Notably, while the share of agricultural exports to other leading destinations declined compared to the previous year, exports to the United States remained stable, showing a slight increase from 6.46% to 6.84%. This steady growth reflects the sustained strength of bilateral agricultural trade between the two nations.

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In FY 2024, India exported 9.83 lakh metric tonnes of agricultural products to the United States, valued at USD 1,960.68 million. The agricultural trade between India and the United States has demonstrated an upward trend, recording a compound annual growth rate (CAGR) of 13.31% since 1990. The highest export quantity was recorded in FY 2012. Overall, India currently exports 42 different agricultural products to the United States, highlighting the depth and diversification of their agricultural trade relationship.

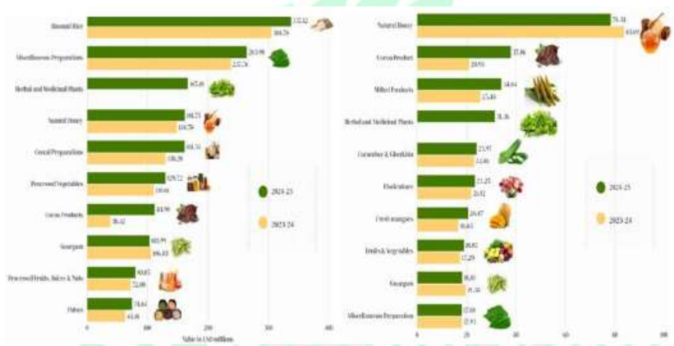
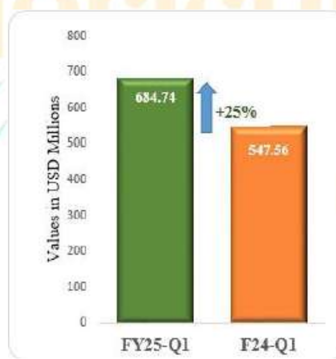


Fig. 2: India's Top 10 Agricultural Exports to USA a) By export value (USD Millions) b) by share of India's Total exports (%)

The major agricultural exports from India to the United States, contributing approximately 81% of the total export value, include Basmati rice, miscellaneous food preparations, herbal and medicinal plants, natural honey, cereal preparations, processed vegetables, cocoa products, guar gum, processed fruits, fruit juices, nuts, and pulses. The United States serves as a key destination for several of these commodities, accounting for 78.34% of India's natural honey exports, 37.86% of cocoa products, and 34.04% of milled products. Notably, exports of herbal and medicinal products have exhibited remarkable growth in the U.S. market, representing 31.36% of India's total agricultural exports in this category. Furthermore, the export value of cocoa products tripled in FY 2024 compared to FY 2023. This substantial share highlights the strong and growing dependence of the U.S. market on Indian agricultural products.

Impact of US Trade policies: Recently, the Trump administration announced plans to impose reciprocal tariffs on Indian goods, citing India's continued purchases of Russian oil and restrictions on U.S. agricultural products in its domestic market. In addition, the United States implemented a 10% universal tariff on all imports effective from April 2025. This measure led to a decline in India's overall exports to the U.S. during the first quarter (Q1) of FY 2025.



	April	May	June	July
FY-25	157.1	185.1	176.5	166.1
FY-24	124.9	148.6	132.0	142.0
FY-23	94.0	107.5	108.3	122.6

Fig. 3: Trends in India's Agricultural Exports to the USA a) FY25-Q1 vs FY24-Q1 b) Month wise comparison of Export values of Q1

Despite this, agricultural exports remained strong, posting a 25% increase compared to Q1 of FY 2024. However, this growth was not reflected in certain key products, with Basmati rice (-15%), milled products (-38%), fresh mangoes (-17%), floriculture (-3%), and alcoholic beverages (-2%) recording declines. Minor exports showed even steeper drops, including fresh vegetables (-13%), cashew kernels (-83%), buffalo meat (-64%), cereals (-84%), and fresh grapes (-61%) compared to Q1 of FY 2024. Moreover, the overall growth may not be sustainable under the current trade conditions. While FY 2023 and FY 2024 showed a steady increase in exports from April to July, FY 2025 experienced a decline in July exports compared to May and June. This drop was mainly observed in key commodities such as Basmati rice, non-Basmati rice, natural honey, herbal and medicinal crops, and cocoa products.

Conclusion

India's agricultural exports to the United States have grown steadily, with products like herbal and medicinal plants, natural honey, and cocoa products performing strongly. The U.S. remains a key market for India's agriculture. However, recent U.S. trade measures, including reciprocal tariffs and the 10% universal tariff, have started affecting exports, especially Basmati rice, milled products, fresh mangoes, floriculture, and minor products. Although overall agricultural exports increased by 25% in Q1 of FY 2025, this growth is uneven and may not continue. The drop in exports in July FY 2025 shows that some key commodities are vulnerable to trade barriers. To sustain growth, India will need to diversify markets and address tariff challenges.

References

Agricultural and Processed Food Products Export Development Authority (APEDA), Ministry of Commerce & Industry, Govt. of India. (https://agriexchange.apeda.gov.in/)

Choi, Y., Acharya, R. N., Devadoss, S. and Regmi, M. (2025). Effects of tariff and non-tariff barriers on India-US agricultural trade. *Applied Economic Perspectives and Policy*, 47(1): 256-274.

Gopalakrishnan, B. N., Gopinath, M. and Kumar, K. (2025). India-United States Agricultural Trade Under the America-First Agenda. *Agribusiness.*

Indigenous Technical Knowledge (ITK) in Managing Insect Pests of Arunachal Pradesh: Sustainable Practices from Tribal Agriculture

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Introduction

Arunachal Pradesh, the north-eastern most state of India, is a biodiversity hotspot and home to more than 26 major tribes with unique cultural and agricultural practices. The hilly terrain, heavy rainfall, and diverse agro-climatic zones make agriculture both challenging and highly diverse. Traditional agriculture here relies heavily on Indigenous Technical Knowledge (ITK) to maintain crop health and productivity. ITK refers to practical, experience-based methods developed over generations to manage pests without relying on synthetic chemicals. These practices are eco-friendly, cost-effective, and adaptable to local conditions. They include cultural, mechanical, botanical, and ecological methods to protect crops, particularly indigenous varieties of rice, maize, millets, pulses, and vegetables. In addition to providing pest control, ITK practices support soil health, biodiversity, and community resilience.

Indigenous Cropping Systems and Pest Ecology

Tribal communities in Arunachal Pradesh have developed cropping systems that naturally reduce pest infestations. Key strategies include:

Jhum (Shifting Cultivation): This system involves rotating crops in different plots, leaving fallow periods between cycles. This disrupts the life cycle of pests and prevents large-scale infestations.

Mixed Cropping: Cereals, pulses, vegetables, and spices are grown together, which confuses pests and attracts natural predators. For example, the Nyishi tribe grows maize intercropped with beans and leafy vegetables, attracting spiders and ladybirds that feed on caterpillars and aphids.

Terrace Farming: Practiced by the Apatani and Adi tribes, terrace farming allows better water management, reducing pests such as stem borers that thrive in stagnant water.

These cropping systems maintain ecological balance by promoting predator-prey relationships, thereby reducing the need for chemical interventions.

Botanical and Natural Pest Management

Plant-based pesticides are a cornerstone of ITK. Common methods include:

Neem (*Azadirachta indica*): Leaves, seeds, and oil are applied to repel or kill caterpillars, aphids, and leaf miners.

Tobacco (*Nicotiana tabacum*): Crushed leaves are sprayed on vegetables to repel sucking pests.

Chili (*Capsicum* spp.) and Garlic (*Allium sativum*)

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: Ground chili and garlic mixtures are used to control pests like aphids, thrips, and beetles.

Aromatic Local Plants: Leaves of Artemisia, Citrus, and Lantana are burned or made into sprays to repel flying insects.

Ash and Cow Urine Mixtures: In Lower Dibang Valley, ash from burnt paddy husks mixed with cow urine is sprayed on paddy crops to control sap-sucking pests.

These botanicals are biodegradable, non-toxic, and environment-friendly, ensuring that beneficial insects are preserved and soils remain fertile.

Mechanical and Ecological Methods

Mechanical and ecological interventions complement botanical methods:

Handpicking and Trapping: Farmers manually remove eggs, larvae, and caterpillars. Sticky traps or colored boards are used to capture pests like fruit flies.

Smoke Fumigation: Burning aromatic plant leaves generates smoke that repels flying pests during critical crop stages.

Flooding and Water Management: Controlled flooding in paddy fields destroys soil-dwelling pests such as stem borers.

Integrated Rice-Fish Systems: In Ziro Valley, small fish introduced in paddy fields consume insect larvae, naturally reducing pest populations.

Trap Crops: Mustard or colocasia is planted around main crops to lure pests away from primary crops, preventing major damage.

These practices illustrate a deep understanding of ecological relationships, using natural methods to maintain pest control.

Observation-Based Pest Forecasting

Tribal farmers rely on environmental cues to forecast pest outbreaks:

Insect Behavior: Early appearance of moths or caterpillars signals potential infestations.

Bird Activity: A sudden increase in insectivorous birds indicates rising pest populations.

Weather Patterns: Humidity, rainfall, and wind changes are monitored to anticipate pest emergence.

Based on these observations, farmers adjust sowing schedules, apply botanical sprays, remove infested plants, or modify irrigation patterns. This preemptive strategy reduces crop losses and ensures sustainable harvests.

Community Practices and Rituals

Pest management is also a social and cultural practice:

Festivals and Rituals: Solung (Adi tribe) and Nyokum (Nyishi tribe) include prayers and offerings for pest-free crops.

Knowledge Sharing: Villagers exchange information about pest infestations and control strategies.

Collective Action: Community members coordinate inspections, pest removal, and protective measures to respond quickly to outbreaks.

These practices strengthen social cohesion, encourage collective responsibility, and reinforce respect for nature.

ITK offers important insights for contemporary farming:

Biodiversity: Mixed cropping and intercropping support natural pest regulation.

Eco-Friendly Pest Control: Botanical sprays and mechanical methods reduce reliance on synthetic chemicals.

Observation-Based Decision Making: Monitoring environmental cues allows timely interventions.

Community Engagement: Collective knowledge and coordinated action enhance resilience.

Integrating ITK with modern scientific approaches can improve food security, minimize environmental pollution, and preserve cultural heritage.

Conclusion

Indigenous Technical Knowledge in Arunachal Pradesh provides sustainable, practical, and environmentally safe solutions for insect pest management. Cultural practices, botanical insecticides, mechanical methods, and ecological interventions collectively reduce pest damage, protect biodiversity, and maintain soil fertility. Preserving and promoting ITK alongside modern agriculture can create resilient, eco-friendly, and productive farming systems, ensuring sustainable livelihoods for tribal communities while safeguarding cultural and ecological heritage.

References

Singh, R. and Tamang, P. (2019). Community-Based Pest Management Practices in Indigenous Agriculture of Northeast India. *Journal of Ethnobiology and Ethnomedicine*, 15(1): 42.

Borah, S. and Dutta, M. (2018). Traditional Knowledge and Practices of Pest Management in North-East India. *International Journal of Agriculture Sciences*, 10(3): 124.

Kalita, P. and Saikia, S. (2015). Indigenous Technical Knowledge (ITK) of Farmers in Arunachal Pradesh for Sustainable Agriculture. *Indian Journal of Traditional Knowledge*, 14(2): 248-256.

Lal, R. and Pandey, S. (2017). Shifting Cultivation (Jhum) and Indigenous Pest Management in Northeast India. *Journal of Rural Development*, 36(4): 489-505.

Modi, R. K. and Deka, R. (2016). Botanical Pesticides and Their Role in Sustainable Pest Management in Tribal Farming Systems of Arunachal Pradesh. *Indian Journal of Entomology*, 78(2): 101-110.

Rao, V. R. and Sharma, P. (2014). Traditional Agricultural Practices of Arunachal Pradesh: Integration of Pest Management with Cultural Practices. *Indian Journal of Traditional Knowledge*, 13(3): 567-575.

Verma, P. and Rajkhowa, D. (2020). Indigenous Knowledge and Eco-Friendly Pest Management in Arunachal Pradesh. *Research Journal of Agriculture and Forestry Sciences* 8(2): 55-63.

FAO (Food and Agriculture Organization). (2013). Indigenous Knowledge and Sustainable Agriculture in Asia and the Pacific. FAO Regional Office for Asia and the Pacific.

Moringa: The Miracle Tree

Kirti Gour, Manisha Rathore and Devi Lal Jat

Abstract

Moringa oleifera, commonly known as the drumstick tree, is increasingly recognized for its exceptional nutritional, medicinal, and ecological value. Native to the Indian subcontinent, it is now cultivated worldwide. Rich in essential nutrients and bioactive compounds, Moringa offers potential in food security, sustainable agriculture, and health care. This article presents a comprehensive review of its botanical features, propagation, nutritional profile, varieties, health and ecological benefits, and future potential in addressing global challenges.

Introduction

Moringa oleifera, commonly known as drumstick or sahjan, is often called the "miracle tree" due to its remarkable nutritional and medicinal properties. Native to India and parts of Africa, it has long been used in traditional diets and herbal medicine. In recent years, moringa has gained global recognition for its role in promoting sustainable, plant-based health solutions. It is rich in essential nutrients like vitamin A, vitamin C, calcium, iron, and antioxidants. Nearly every part of the tree leaves, pods, seeds, and even bark offers health and industrial benefits. India remains the largest producer, with over 2.6 million tonnes grown annually across states like Tamil Nadu, Andhra Pradesh, Maharashtra, and Uttar Pradesh. Its adaptability to poor soils and drought makes it a key crop for climate-resilient agriculture and rural income generation. Moringa's growing demand in the food, health, cosmetic, and biofuel industries further highlights its economic and ecological value.

Botanical Description: *Moringa oleifera* belongs to the family Moringaceae. It is a soft-wooded, deciduous perennial tree that grows up to 10-12 meters in height. The trunk is soft with a whitish bark and a prominent taproot system. Leaves are compound and tripinnate with small, oval-shaped leaflets. The plant produces small, white, fragrant flowers in clusters. The fruit is a long, slender pod (30-45 cm), known as a "drumstick," containing round seeds with wing-like structures. Moringa adapts well to tropical and subtropical climates, preferring sandy or loamy soils with a pH between 6.3 and 7.0.

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Nutritional Value: Moringa is widely recognized as one of the most nutrient-dense plants in the world, earning it the label of a "super food." The leaves, in particular, are an abundant source of essential vitamins such as A, C, E, and several B-complex vitamins. In terms of minerals. Moringa is also a rare plant-based source of all nine essential amino acids, making it a complete protein a crucial attribute for vegetarian and vegan diets.

Table 1: Nutritional Composition of Moringa Leaves (per 100 g of Edible Portion)

Nutrient	Amount	Remarks / Significance
Energy	64 kcal	Low-calorie, nutrient-dense food
Protein	27.1 g	Complete plant-based protein with all essential amino acids
Carbohydrates	8.3 g	Source of dietary fiber and energy
Fiber	2.0 g	Promotes digestion and gut health
Calcium (Ca)	2,700 mg	Strengthens bones and teeth
Iron (Fe)	28 mg	Prevents anaemia and boosts haemoglobin
Potassium (K)	1,324 mg	Maintains blood pressure and heart function
Magnesium (Mg)	368 mg	Supports muscle and nerve function
Zinc (Zn)	3.3 mg	Enhances immunity and metabolism
Vitamin A (β-carotene)	10 mg (16,000 IU)	Essential for vision and immunity
Vitamin C	17 mg	Boosts immunity and antioxidant defense
B Vitamins (B_1, B_2, B_3)	1.2 mg, 0.76 mg, 2.6 mg	Support energy metabolism
Amino Acids	All 9 essential amino acids	High-quality protein source

Climate and soil: Moringa (*Moringa oleifera*) thrives best in tropical and subtropical climates with temperatures ranging between 25°C to 35°C (77°F to 95°F). It prefers regions with moderate rainfall, ideally between 250 mm to 1500 mm annually, though it is drought-tolerant once established.

Moringa grows well in well-drained sandy or loamy soils with a pH between 6.3 and 7.0, avoiding waterlogged or heavy clay soils. The tree favors sunny locations with good air circulation and can tolerate poor soil conditions, making it suitable for arid and semi-arid areas. Proper soil drainage and minimal frost exposure are key for optimal growth and productivity.

Propagation Methods

Moringa is propagated through both seeds and stem cuttings:

Seed Propagation: Direct seeding is common. Seeds are sown 2-3 cm deep, spaced 1-2 meters apart. Germination occurs within 1-2 weeks.

Vegetative Propagation (Cuttings): Stem cuttings (1-1.5 m long, 4-5 cm thick) are planted directly into moist soil. This method is suitable for faster maturity and higher leaf yield. Moringa requires minimal maintenance and grows well even in degraded soils, making it ideal for low-input and organic farming systems.

Popular Varieties

PKM-1: High-yielding variety developed in Tamil Nadu; ideal for commercial pod production.

PKM-2: Improved variety with larger pods and higher leaf biomass.

ODC-3: Suited for semi-arid regions and leaf production.

Jaffna: Grown in Sri Lanka and India; known for thick, tender pods.

Periyakulam Local: Dual-purpose type used for leaves and fruits.

Benefits of Moringa

Health Benefits

Boosts Immunity: High vitamin C and A content strengthens immune defense.

Regulates Blood Sugar: Helps in managing diabetes by reducing glucose levels.

Lowers Cholesterol: Reduces LDL (bad cholesterol), promoting heart health.

Anti-inflammatory Properties: Effective against arthritis, asthma, and chronic inflammation.

Antioxidant-Rich: Contains quercetin, chlorogenic acid, and other antioxidants that protect cells.

Supports Liver Function: Detoxifies and protects the liver against damage.

Aids Digestion: High fiber content improves gut health and relieves constipation.

Enhances Skin & Hair: Promotes healthy skin and hair due to vitamin E and omega-3s.

Supports Anemia Treatment: High iron content helps improve hemoglobin levels.

Ecological Benefits

Soil Conservation: Prevents erosion and improves soil structure through deep root systems.

Water Purification: Crushed seeds can clarify and disinfect water.

Drought Resistance: Thrives in arid and semi-arid regions with minimal water input.

Green Manure and Mulch: Leaves enhance soil fertility when used as organic matter.

Agroforestry Component: Acts as a shade crop and windbreak in mixed farming systems.

Economic and Social Benefits

Marketable Products: Moringa leaves, powders, oils, teas, and capsules are in high global demand.

Income for Farmers: High yield, low maintenance crop with year-round harvesting potential.

Women Empowerment: Leaf processing and small-scale moringa businesses support rural women.

Nutrition Programs: Used in public health initiatives to combat malnutrition in children and pregnant women.

Future Prospects

Moringa has strong potential to contribute to several global development goals. As climate change affects food production, moringa stands out as a resilient crop adaptable to extreme weather and low soil fertility. Its incorporation into national food and nutrition security programs can help reduce micronutrient deficiencies. In the pharmaceutical sector, bioactive compounds from moringa are under study for potential applications in treating diabetes, cancer, and neurodegenerative diseases. Its oil is a sustainable alternative to synthetic lubricants and biodiesel, adding to its industrial appeal Moringa has immense potential to support India's sustainable development goals. India is the largest producer of moringa, with an estimated cultivation area of over 200,000 hectares, mainly in states like Uttar Pradesh, Tamil Nadu, and Odisha. Its resilience to drought and poor soils makes it ideal for regions affected by climate change. Moringa is rich in vitamins and minerals, helping to combat widespread micronutrient deficiencies in India, where nearly 50% of children suffer from anemia. The Indian government promotes moringa through programs supporting women farmers and nutrition initiatives. For example, in Lucknow, Dr. Kamini Singh's moringa project empowers more than 1,000 women, boosting livelihoods and nutrition. With growing industrial uses, including bioactive compounds and oil for biodiesel, moringa is becoming a key crop for climate-smart agriculture and rural development in India.

Conclusion

Moringa oleifera truly lives up to its reputation as a miracle tree. Its rapid growth, adaptability, and remarkable nutritional and medicinal properties make it a strategic crop for addressing malnutrition, poverty, and environmental degradation. Integrating moringa into food systems, public health strategies, and agroecological practices can lead to more resilient communities and eco-systems. With proper policy support and awareness, moringa can be a game-changer in promoting a healthy and sustainable future.

References

Anwar, F., Latif, S., Ashraf, M. and Gilani, A. H. (2007). *Moringa oleifera:* A food plant with multiple medicinal uses. *Phytotherapy Research*, 21(1): 17-25.

Leone, A., Spada, A., Battezzati, A., Schiraldi, A., Aristil, J. and Bertoli, S. (2015). Cultivation, genetic, ethnopharmacology, phytochemistry and pharmacology of *Moringa oleifera* leaves: An overview. *International Journal of Molecular Sciences*, 16(6): 12791-12835.

Fahey, J. W. (2005). *Moringa oleifera:* A review of the medical evidence for its nutritional, therapeutic, and prophylactic properties. *Trees for Life Journal*, 1(5).

Gopalakrishnan, L., Doriya, K. and Kumar, D. S. (2016). *Moringa oleifera:* A review on nutritive importance and its medicinal application. *Food Science and Human Wellness*, 5(2): 49-56.

Jaiswal, D., Rai, P. K., Kumar, A., Mehta, S. and Watal, G. (2009). Effect of Moringa oleifera leaves aqueous extract therapy on hyper-glycemic rats. *Journal of Ethnopharma-cology*, 123(3): 392-396.

Makkar, H. P. S. and Becker, K. (1997). Nutrients and antiquality factors in different morpho-logical parts of the *Moringa tree*. *Journal of Agricultural Science*, 128(3): 311-322.

A World without Bees: The Silent Crisis behind Our Food

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Bees are nature's most efficient pollinators. They are responsible for the fertilization of more than 85 percent of flowering plants and over one-third of global food crops. Each time a bee visits a flower to collect nectar, it also transfers pollen from one flower to another, ensuring seed formation and fruit development. This simple act keeps our ecosystems alive and our food supply abundant. There are more than 20,000 species of bees around the world. Among them, the honeybee (*Apis mellifera*) plays the most vital role in agriculture. But wild bees such as bumblebees, leafcutter bees, and solitary bees are equally crucial for pollinating native plants and maintaining biodiversity. Bees are not just about honey; they are about survival. If bees disappear, the impact will ripple across the planet. Fruits and vegetables would become scarce and expensive. Livestock feed crops like alfalfa and clover would decline, leading to reduced milk and meat production. Plant reproduction in forests and grasslands would be disrupted, affecting wildlife that depends on those plants for food. Without bees, the delicate balance of life on Earth would collapse.

In recent decades, bee populations have been declining at alarming rates a phenomenon scientists call Colony Collapse Disorder (CCD). Several factors contribute to this crisis. Pesticide exposure can disorient bees, weaken their immunity, or even kill them. Habitat loss due to urbanization, monocropping, and deforestation has destroyed the natural environments bees rely on for nesting and foraging. Climate change disturbs flowering cycles and nectar availability, while pests and diseases such as *Varroa destructor* mites and fungal infections further weaken colonies. A world without bees would mean reduced crop yields, nutritional decline, economic loss, and environmental imbalance. Up to 75 percent of food crops depend on pollinators. Fruits, nuts, and vegetables rich in vitamins and antioxidants would disappear from our diets. Global agriculture could lose hundreds of billions of dollars annually, and pollination-dependent ecosystems would degrade.

While the challenge is huge, small actions can bring big change. Plant bee-friendly flowers like marigold, sunflower, mustard, and basil in gardens or balconies. Avoid harmful pesticides and opt for eco-friendly alternatives such as neem-based products. Support local beekeepers by purchasing local honey. Protect natural habitats and educate communities

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about the importance of pollinators. Schools, farmers, and citizens can join campaigns like Save the Pollinators or Adopt a Beehive.

Saving bees is not just about protecting a single species; it is about preserving biodiversity and food security. Every buzzing bee is a reminder that nature's smallest workers sustain the largest systems on Earth. If each of us takes small steps to create a bee-friendly world, we can ensure that future generations will continue to enjoy the fruits of these amazing insects' labor.

Let us imagine not a world without bees, but a world alive with their gentle hum where fields bloom, fruits flourish, and life continues to thrive.

"If the bee disappears from the surface of the Earth, man would have no more than four years left to live." Albert Einstein.

Silent Genes, Stronger Crops: The RNAi Revolution in Plant Breeding

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Abstract

RNA interference (RNAi) has revolutionized plant breeding by offering a precise, stable, and environmentally friendly method for gene silencing. This technology enables targeted manipulation of gene expression to enhance crop traits such as disease resistance, stress tolerance, nutritional quality, and post-harvest longevity. RNAi operates through diverse small RNA pathways including siRNAs, miRNAs, tasiRNAs, and rasiRNAs each contributing uniquely to gene regulation. Its applications span transgenic and non-transgenic approaches, including host-induced and spray-induced gene silencing. India has made notable strides in RNAi research, applying it to combat viral infections in black gram and banana, improve oil quality in peanuts, and regulate flowering in ornamentals like chrysanthemum. The development of dsRNA-based biopesticides and RNAi-enabled crop varieties underscores its potential to transform agriculture sustainably. This article highlights recent achievements and future prospects of RNAi in plant breeding, emphasizing its role in addressing global food security and environmental challenges.

Introduction

Scientific discoveries often lead to remarkable advances in basic research that ultimately benefit human welfare. One such breakthrough is RNA interference (RNAi), a gene regulation mechanism that controls gene expression at the post-transcriptional level. RNA interference (RNAi) has emerged as a transformative tool in plant breeding, offering a precise method for silencing specific genes to develop crops with enhanced traits. Since its discovery, RNAi has shown immense potential in expanding crop improvement strategies (Napoli *et al*., 1990). Owing to its precision, efficiency, and stability (Choudhary *et al*., 2018), RNAi is now considered a valuable tool for promoting sustainable crop production and protection with minimal environmental impact (Secic and Kogel, 2021). RNAi is widely exploited in both host-induced gene silencing and spray-induced gene silencing approaches to target pests and pathogens, as well as to manipulate plant gene expression (Sang and Kim, 2020). It has been successfully applied to develop crops with improved nutritional quality, male sterility, stress tolerance (abiotic and biotic), delayed ripening, modified plant architecture, and other desirable traits (Kamthan *et al*., 2015). Beyond conventional breeding, modern biotechnology employs sophisticated RNA-based tools for enhancing agricultural productivity. These include transgenic approaches that utilize RNAi, microRNA

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(miRNAs), artificial miRNAs (amiRNAs), and designer transcription activator-like effectors (dTALEs) for precise regulation of gene expression. Plants naturally harbour multiple RNA silencing pathways, such as those mediated by miRNAs, repeat-associated siRNAs (rasiRNAs), trans-acting siRNAs (tasiRNAs), and exogenous siRNAs (exosiRNAs) (Guo *et al*., 2016). For instance, tasiRNAs are 21-nt secondary siRNAs generated through DCL4 processing of dsRNA synthesized by RDR6 from miRNA-cleaved TAS fragments (Eamens *et al*., 2008). While siRNAs mainly promote RNA degradation via the RNAi pathway, miRNAs modulate mRNA translation (Ferguson *et al*., 2020). Similarly, rasiRNAs (24 nt) are produced through the coordinated activity of Pol IV, RDR2, and DCL3 on repetitive DNA (Matzke *et al*., 2015), whereas miRNAs arise from DCL1 processing of self-folding RNAs transcribed from MIR genes. ExosiRNA processing involves both DCL4 and DCL3, overlapping with tasiRNA and rasiRNA pathways (Guo *et al*., 2016). RNAi through self-complementary hairpin RNAs (hpRNAs) is a robust strategy for inducing dsRNA-mediated silencing. Meanwhile, antisense RNAs, complementary to target mRNAs, can alter splicing, induce RNase H–mediated degradation, or block translation. Thus, while all small RNAs contribute to gene regulation, they differ in their processing pathways.

RNAi can also be delivered through plant-incorporated protectants or external applications. Non-transformative approaches, such as sprayable RNAs, function as direct control agents, resistance suppressors, or developmental disruptors. Although transgenic RNAi strategies provide strong protection against specific pests, they are often restricted by regulatory, political, or technical constraints (Baum *et al*., 2007). In such cases, topical application of dsRNA offers a practical alternative, inducing pathogen resistance without requiring transformation.

Most fungal species possess conserved RNAi machinery including Argonaute, RdRP, and Dicer making them suitable targets for RNAi-based strategies (Meng *et al*., 2017). Similarly, RNAi has been applied against diverse viral and fungal phytopathogens by disrupting their replication processes. Since its discovery, RNAi has emerged as a powerful tool for functional genomics, enabling the study of host gene function while also enhancing crop traits related to yield, stress tolerance, and quality attributes (Kamthan *et al*., 2015).

India has made significant achievements in plant breeding using RNA interference (RNAi) technology, primarily focused on enhancing disease resistance and improving crop traits. Research has demonstrated the successful application of RNAi to suppress genes responsible for viral infections, such as the Mungbean Yellow Mosaic India Virus (MYMIV) in black gram (*Vigna mungo*), leading to plant recovery through gene silencing. Using black gram as a study system, Pooggin *et al*. (2003) have discovered that the DNA of a replicating virus can also be a target of RNAi.

They have observed recovery of *Vigna mungo* from MYMIV infection by silencing the gene associated with bidirectional promoter through RNAi approach. This technology has also been employed to develop resistance against the Banana Bract Mosaic Virus (BBrMV), a major threat to banana cultivation in Southeast Asia and India. Now, RNAi can be used in production of blue rose by suppressing cyanidin genes; generating low lignin content jute varieties for high-quality paper; healthier oil production by suppressing the enzyme that converts oleic acid into a different fatty acid; regulating flowering time in crops. In ornamental crops, RNAi has been used to manipulate flowering time in chrysanthemum. Flowering time is the main determinant of successful commercial plants, and the development of early-flowering cultivars helps meet consumers' needs by allowing plants to bear more flowers or be produced in sufficient numbers for the celebration of particular festivals. Transgenic chrysanthemum plants with suppressed Cm-BBX24 expression flowered approximately 20 days earlier than wild-type plants under long-day conditions, which is crucial for meeting market demands for festival-specific blooms (Su *et al.,* 2019). Furthermore, RNAi has been used to modify plant morphology and improve stress tolerance, with studies showing that changes in gibberellic acid (GA) biosynthesis due to gene suppression can enhance responses to salt and drought stresses.

India's research institutions, including the National Institute of Plant Genome Research and Jamia Hamdard University, are actively involved in advancing RNAi applications for sustainable agriculture, particularly in developing dsRNA-based biopesticides as a safer alternative to chemical pesticides. These efforts are part of a broader strategy to combat biotic stresses like insects, fungi, and nematodes, which cause substantial crop losses annually. The use of RNAi in host-induced gene silencing (HIGS) and spray-induced gene silencing (SIGS) is being explored to create targeted, environmentally friendly pest management solutions

Recent achievements

Recent achievements include improving resistance to biotic and abiotic stresses, enhancing nutritional quality, modifying key plant characteristics and post-harvest improvements.

Biotic stress resistance

RNAi has enabled the development of crops with enhanced defences against insects, viruses, fungi, and parasitic weeds.

Insect resistance: Scientists have engineered crop plants to produce double-stranded RNA (dsRNA) that, when ingested by pests, silences genes essential for the insects' growth, development, or survival.

- ✓ **Western corn rootworm:** Transgenic maize has been developed that expresses dsRNA targeting a gene in this pest, resulting in the silencing of that gene and significantly reduced crop damage.
- ✓ **Cotton bollworm:** In cotton, RNAi has been used to target a gene that confers resistance to a toxic plant compound, making the pest more susceptible and reducing its survival.

Disease resistance: RNAi is used to target viral, fungal, and bacterial pathogens directly, preventing them from replicating and causing infection.

- ✓ **Viral pathogens:** RNAi has been employed to create potatoes resistant to the Potato virus Y and cassava resistant to Cassava brown streak disease. This is achieved by silencing genes crucial for the virus's replication inside the plant.
- ✓ **Fungal pathogens:** Strategies like spray-induced gene silencing (SIGS), where dsRNA is sprayed directly onto plants, have been used to protect crops such as barley and wheat from fungal infections like powdery mildew and head blight.

Abiotic stress tolerance

Breeding for tolerance to environmental stressors is a major application of RNAi, helping to maintain crop yields under challenging conditions.

Drought tolerance: In rice, RNAi has been used to suppress genes that negatively regulate drought-response pathways. The resulting rice varieties maintain productivity even under water-limited conditions.

Salinity and temperature tolerance: By silencing genes that cause sensitivity to stress, RNAi helps breeders develop crops that are more resilient to heat, cold, and high salinity.

Enhanced food quality and nutrition

RNAi allows breeders to alter a crop's metabolic pathways, boosting nutritional value and eliminating undesirable compounds.

Nutrient biofortification

Increased antioxidants: In tomatoes, RNAi has been used to silence genes that negatively regulate flavonoid and carotenoid synthesis, increasing the content of these beneficial antioxidants.

Reduced phytic acid: RNAi has produced wheat grains with reduced antinutrient phytic acid, resulting in higher levels of absorbable zinc and iron.

Reduced allergens and toxins

Allergen reduction: RNAi has been applied to reduce or eliminate allergens in food crops, including a major allergen in apples (Mal d1) and peanut allergens (Ara h 2).

Toxin elimination: In cotton, RNAi-mediated gene silencing has produced ultra-low gossypol cotton seed, making the protein-rich seeds safe for human consumption.

Improved oil quality

In peanut and soybean, RNAi has been used to silence genes involved in fatty acid metabolism, leading to a more desirable oil composition with higher oleic acid content and better stability.

Agronomic and post-harvest improvements

RNAi also enables changes to a plant's physical characteristics to improve crop production and marketability.

Extended shelf life: In tomatoes and bananas, RNAi-mediated suppression of ripening-related genes has successfully extended the shelf life of the fruit, reducing post-harvest waste.

Seedless fruit: By silencing genes that play a role in seed development, researchers have used RNAi to develop parthenocarpic (seedless) varieties of tomatoes and other fruits.

Modified plant architecture: Altering genes that regulate meristem activity and cell elongation can produce changes in plant height, branching, and leaf structure, with a resulting increase in biomass and yield.

Modified flower color: For ornamental plants like petunias and gentians, RNAi has been used to alter the flavonoid pathway to create unique and desirable flower colors.

Conclusion

RNAi stands at the forefront of modern plant biotechnology, offering unparalleled precision in gene regulation for crop improvement. Its versatility across biotic and abiotic stress management, nutritional enhancement, and agronomic traits makes it a cornerstone of sustainable agriculture. The integration of RNAi into breeding programs especially through non-transgenic methods like sprayable RNAs paves the way for eco-friendly pest control and resilient crop varieties. India's contributions, from virus-resistant legumes to early-flowering ornamentals, exemplify the transformative impact of RNAi. As regulatory frameworks evolve and delivery technologies advance, RNAi is poised to become an indispensable tool in global efforts to ensure food security, reduce chemical inputs, and meet the demands of a changing climate.

References

Baum, J. A., Bogaert, T., Clinton, W., Heck, G. R., Feldmann, P., Ilagan, O., Johnson, S., Plaeti-nck, G., Munyikwa, T., Pleau, M., Vaughn, T. and Roberts, J. (2007). Control of coleopteran insect pests through RNA interference. *Nature Biotechnology,* 25: 1322-1326.

Eamens, A., Wang, M. B., Smith, N. A. and Waterhouse, P. M. (2008). RNA silencing in plants: yesterday, today, and tomorrow. *Plant Physiology,* 147: 456.

Guo, Q., Liu, Q., Smith, N. A., Liang, G. and Wang, M. B. (2016). RNA silencing in plants: mechanisms, technologies and applications in horticultural crops. *Current Genomics,* 17: 476-489.

Kamthan, A., Chaudhuri, A. and Kamthan, M. (2015). Plant small RNAs: recent develop-ments and applications for crop improve-ment. *International Journal of Advanced Research in Chemical Sciences*, 5(5): 1936-1940.

Matzke, M. A., Kanno, T. and Matzke, A. J. (2015). M. RNA-directed DNA methylation: the evolution of a complex epigenetic pathway in flowering plants. *Annual Reviews in Plant Biology,* 66: 243-267.

Meng, J., Lei, J., Davitt, A., Holt, J. R., Huang, J. and Gold, R. (2017). Suppressing tawny crazy ant (*Nylanderia fulva*) by RNAi technology. *Insect Science,* 27(1): 113-121.

Pooggin, M., Shivaprasad, P. V., Veluthambi, K. and Hohn, T. (2003). RNAi targeting of DNA virus in plants. *Nature Biotechnology,* 21: 131-132.

Napoli, C., Lemieux, C. and Jorgensen, R. (1990). Introduction of a Chimeric Chalcone Synthase Gene into Petunia Results in Reversible Co-Suppression of Homologous Genes in trans. *Plant Cell*, 2(4): 279-289.

Ferguson, C., Echeverria, D., Hassler, M., Ly, S. and Khvorova, A. (2020). Cell Type Impacts Accessibility of mRNA to Silencing by RNA Interference. Molecular Therapy: Nucleic Acids. Vol. 21. An open access article under the CC BY license (http://creativecommons.org/licenses/by/4.0/).

Sang Hyunkyu and Kim Jeong-Il. (2020). Advanced strategies to control plant pathogenic fungi by host-induced gene silencing (HIGS) and spray-induced gene silencing (SIGS). *Plant Biotechnology Reports,* 14: 1-8.

Secic, E. and Kogel, K. H. (2021). Requirements for fungal uptake of dsRNA and gene silencing in RNAi-based crop protection strategies. *Current Opinion in Biotechnology*, 70:136-142.

Choudhary, S., Jain, D., Mintu, Meena, R., Verma, A. K. and Sharma, R. S. (2018). Gene Silencing in Horticultural Transgenic Crops. *Genetic Engineering of Horticultural Crops*, 47-61.

Su, Jiangshuo, Jiang, J., Zhang, F., Liu, Y., Ding, L., Chen, S. and Chen, F. (2019). Current achievements and future prospects in the genetic breeding of chrysanthemum: a review. *Horticulture Research*, 6:109.

Seed Health and Seed-Borne Diseases

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Abstract

Seed health plays a crucial role in determining crop establishment, productivity, and disease management. Seeds may carry various pathogens such as fungi, bacteria, viruses, and nematodes, which can reduce germination, cause seedling mortality, and spread diseases to new areas. Seed-borne diseases are often hidden but can result in severe yield losses if not managed properly. Maintaining seed health through detection, certification, and treatment is vital for sustainable agriculture.

Introduction

Seed health refers to the presence or absence of disease-causing organisms in or on seeds. Healthy seeds ensure better germination, seedling vigor, and high yield potential. Seed-borne diseases, on the other hand, are infections transmitted through seeds, either externally on the seed coat or internally in seed tissues.

Common Seed-Borne Pathogens and Diseases

Fungi: *Fusarium*, *Alternaria*, *Ascochyta*, *Tilletia* (e.g., common bunt of wheat).

Bacteria: *Xanthomonas*, *Pseudomonas* species.

Viruses: Bean common mosaic virus, Tomato mosaic virus.

Nematodes: *Anguina* and *Aphelenchoides* species.

These pathogens cause seed rot, damping-off, discoloration, and reduced seed vigor.

Detection Methods

- ✓ Blotter method and agar plate method are traditional approaches for fungal detection.
- ✓ Serological (ELISA) and molecular methods (PCR, LAMP) offer precise identification of bacteria and viruses.
- ✓ Visual examination and germination tests are used for routine health testing.

Management of Seed-Borne Diseases

- ✓ Use of certified, disease-free seed.
- ✓ Seed treatments with fungicides (thiram, captan) or biocontrol agents (*Trichoderma* spp.).
- ✓ Hot water or dry heat treatment for internal pathogens.
- ✓ Proper storage under low humidity to avoid mold growth.
- ✓ Adoption of resistant varieties and crop rotation

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to break disease cycles.

Conclusion

Seed health management is the first step toward achieving healthy crops and sustainable yields. Regular testing, effective seed treatment, and the use of pathogen-free seed lots are essential to minimize the impact of seed-borne diseases.

References

Agrios, G. N. (2015). Plant Pathology (5th ed.). Elsevier Academic Press.

Neergaard, P. (1977). Seed Pathology (Vol. 1 & 2). Macmillan Press.

International Seed Testing Association (ISTA). (2020). *Seed Health Testing Methods*. Zurich, Switzerland.

Kumar, R. and Sharma, P. (2023). Seed-borne fungal pathogens and their management. *The Pharma Innovation Journal*, 12(12): 892-897.

Agrarian Distress and Farmer Suicides: A Sociological Perspective

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Abstract

Agricultural distress in India has become a significant societal issue, deeply interconnected with economic, ecological, cultural, and structural factors. This article examines the crises characterized by diminishing agricultural revenues, escalating debt, crop failures, the breakdown of institutional credit, and market volatility, which result in significant economic distress and profound emotional suffering, frequently culminating in the tragic occurrence of farmer suicides. It looks at the main structural causes, the roles of caste and class, cultural-emotional aspects, and the larger social fabric of rural India through a sociological lens. It also talks about ways to cope, gaps in policy, and the need for coordinated solutions that deal with both the economic and social aspects of rural distress.

Introduction

Agriculture is still an important part of India's rural economy and social life. But Indian farming has been under more and more stress in the last few decades because of things like smaller landholdings, higher input costs, unpredictable weather, limited institutional support and markets that change quickly. These stresses all add up to what is commonly called "agrarian distress." This is a problem that affects more than just the economy; it also affects social relationships, identity, dignity, and health. Research indicates that times of hardship correlate with increased suicide rates among farmers and agricultural laborers. A 2021 anthropological study indicated that between 1995 and 2018, around 400,000 farmers in India killed themselves, or about 48 a day. A lot of these farmers were from castes that were already socially marginalized. This article looks at how agrarian suffering becomes part of society and can even lead to death in the worst circumstances.

Structural and economic dimensions of agrarian distress

Unstable farm economics are a major cause of the agrarian crisis. This includes small and marginal holdings, rising costs of seeds, fertilizers, and energy, and low returns on crops. One study, for instance, says that farmers who own less than 1-2 hectares and are in debt are more likely to kill themselves. Additionally, institutional credit has diminished in several distress-prone regions, with private moneylenders or informal lending prevailing frequently at elevated interest rates. The failure of cooperative credit institutions in places like Vidarbha and Marathwada in Maharashtra is intimately linked to the high number of suicides. Market variables also play a role; for example, low coverage of the Minimum Support Price (MSP), policies for

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exporting and importing goods, and not buying specific crops make people more vulnerable. Farmers that don't have buffers are even more at danger from environmental hazards like drought, unpredictable rainfall, and soil deterioration. These things together make a “risk vortex” where economic collapse is almost certain.

Socio-cultural and identity factors

Farming in India isn't just a job; it's tied to social identity, status, family honor, and passing down traditions from one generation to the next. For a lot of farmers, land is more than just money; it's their pride, their tradition, and their place in society. The failure of farming viability has emotional and social significance. In India's cotton belt, researchers discovered that farmers faced not only financial debt but also a “moral debt,”" characterized by sentiments of guilt, humiliation, and failure within familial and community networks. In these situations, suicide is seen as both an act of despair and a way to end a long history of humiliation. Castes and class also have a role: a study found that most of the suicides it looked at were from backward castes (Dalit farmers). This shows how being socially vulnerable makes agrarian hardship worse. Land fragmentation and unequal access to resources also follow caste and class lines, making things worse for already vulnerable people.

Interplay of institutions, policy and social support

The success or failure of institutions is very important. When cooperative banks or primary agricultural credit societies don't work, farmers can't get cheap loans, and things get worse. Smallholders typically don't get social support services including extension services, market linkages, crop insurance, and relief measures, or they don't work well. From a sociological point of view, this means that farmers feel alone: they are both economically weak and socially isolated. In many places, community ties, informal networks of solidarity, and collective action have all gotten weaker. This has made social capital less useful. From a sociological standpoint, agrarian distress signifies the deterioration of collective resilience.

Agrarian distress as a social phenomenon leading to suicide

Putting the pieces together: the economic, structural, and social aspects of anguish build up in some people and societies until they reach the tragic end of suicide. Sociological study underscores the influence of cumulative influences on the subjective experience of hopelessness. Kishore and Jadhav (2021) stated, “financial and moral debt... engender a profound sense of hopelessness in the Self.” The concept of “socially toxic landscapes,” wherein the farmer's surroundings become characterized by shame, marginalization, and incessant pressure, encapsulates this dynamic. Suicide, thus, transcends individual tragedy, emerging as an indicator of a fractured agricultural social system. The policy responses frequently regard it as an individual mental health concern or economic failure; however, a sociological perspective uncovers more profound origins in social structure, identity, and community disintegration.

Consequences and implications for rural society

The effects of farmer suicides and agrarian distress are felt by families, communities, and generations. Widowhood, child labor, migration, land abandonment, and psychological trauma become prevalent. Research indicates that for each suicide, families experience financial loss, social exclusion, and diminished human capital. The social fabric of rural areas is fraying: people don't trust institutions as much, people don't work together as much, and cycles of distressed farming become more common. Additionally, the elevated prevalence within socially marginalized groups exacerbates caste and class stratifications. People typically use coping mechanisms like moving to a new place or branching out into non-farm labor, but these strategies can have societal consequences, such as losing their identity, causing conflict across generations, and causing social dislocation.

Policy suggestions from a sociological viewpoint

From a social standpoint, solutions must extend beyond just temporary financial assistance or loan forgiveness. They should work to reconstruct the social and institutional systems that support farming. Some important directions are:

- ✓ Making cooperative and institutional credit networks stronger so that small and marginal farmers may get to them quickly and affordably.
- ✓ Making sure that procurement and market support (including MSP coverage) are available for a wider range of crops to make the market less vulnerable.
- ✓ Helping groups of people work together, such farmer producer organizations (FPOs), cooperatives, and community resource groups that build social capital and give each other support.
- ✓ Adding psychosocial assistance and rural mental health outreach to agricultural extension services, since stress is often emotional and social.
- ✓ Changes to land and resources to fix problems with fragmentation, unequal access, and caste/class differences in farming.
- ✓ Encouraging farmers to have more than one way to make a living and to have other jobs to lower their risk of farming only one crop.
- ✓ Finally, involving farmers and communities in the creation of policies treating them as active participants instead of passive recipients helps restore their agency, dignity, and trust.

Conclusion

The agrarian distress and the associated incidence of farmer suicides in India are not merely economic issues that can be addressed solely through loans or subsidies. They are profoundly sociological, grounded in social identity, power dynamics, institutional shortcomings, emotional trauma, and community fragmentation. A sociologically educated perspective acknowledges that farmers function within networks of family, caste/class, land, and community; the disintegration or oppression of these networks renders existence untenable. To solve the situation, we need to change the way things are done, bring people together, and give people mental health help. The way forward requires policies that are both economically sound and socially aware. These policies should not only bring back farmers' incomes, but also give rural communities back their dignity, agency, and optimism.

References

Ahoy, P. (2016). Agrarian Crisis India: An Aftermath of the New Economic Reforms. *International Journal of Sociology and Social Anthropology*, 1(1): 91-98.

Chaithanya, L. K., Reddy, G. S., Barua, S., J., A. and Reddy, M. (2024). Agrarian distress in Indian agriculture: Causes, socio-economic conseq-uences and coping strategies. *Asian Journal of Agricultural Extension, Economics & Sociology*, 42(9): 50-57.

Kannuri, N. K. and Jadhav, S. (2021). Cultivating distress: Cotton, caste and farmer suicides in India. *Anthropology & Medicine*, 28(4): 558-575.

Singh, L., Bhangoo, K. S. and Sharma, R. (2020). Agrarian Distress and Farmer Suicides in North India (2nd ed.). Routledge.

Lamba, E., Sharma, T. and Kaur, B. (2024). Unravelling agrarian distress in India: A comprehensive analysis of causes and manifestations. *International Journal of Agriculture Extension and Social Develop-ment*, 7(3): 598-608.

Farmer suicides in India. data. (n.d.). *Legacy IAS*.

Vertical and Urban Farming: The Future of Sustainable Agriculture

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Introduction

Vertical and urban farming are key to future sustainable agriculture because they address challenges like land scarcity and water use by producing food in stacked layers within controlled, urban environments. These methods reduce transportation emissions by locating farms near consumers, improve food security through local production, and minimize environmental impact by eliminating pesticides and using less water. While requiring advanced technologies and higher initial energy costs, ongoing innovations and government support are making vertical farming a vital component of a more resilient and sustainable global food system. Vertical and Urban Farming use innovative techniques like hydroponics and aeroponics to grow crops efficiently in cities. These methods save space, reduce water consumption, and offer fresh produce year round.

Vertical Farming: Vertical farming is a modern agricultural technique where crops are grown in stacked layers, often inside buildings, shipping containers, or specially designed vertical structures. It uses controlled environments, hydroponics, aeroponics, and LED lighting to provide optimal conditions for plant growth. This farming method uses Controlled Environment Agriculture (CEA) technology to monitor required humidity, temperature, gases, and light in indoor conditions. For instance, farmers use artificial lighting and metal reflectors to mimic natural sunlight.

Urban Farming: Urban farming involves growing crops and raising livestock in cities or densely populated areas. This includes rooftop gardens, community farms, hydroponic greenhouses, and small-scale farming operations in urban spaces. It helps utilize unused spaces for food production while promoting local and sustainable agriculture.

Urban agriculture (UA): The growing of plants and rearing of livestock within a city (intra-urban) or on the areas surrounding the cities (Peri-urban agriculture), involving input provision and processing of raw materials into edible forms followed by marketing activities.

Vertical farming save water

Vertical farming uses hydroponic, aeroponic, and aquaponic systems, which recycle water efficiently. These methods use 90-95% less water than traditional soil-based farming.

Importance of Vertical and Urban Farming

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Land Shortage Solutions: With increasing urbanization, farmland is shrinking. Vertical and urban farming make use of unused buildings, rooftops, and indoor spaces to grow food efficiently.

Climate Change Resilience: Traditional agriculture is highly dependent on weather conditions, but controlled environments in vertical farming protect crops from climate-related challenges like droughts, floods, and temperature fluctuations.

Food Security in Cities: By growing food closer to consumers, urban and vertical farming reduce dependency on rural farms, ensuring a steady supply of fresh produce.

Efficient Resource Use: These methods use less land, water and fertilizers reducing the environmental footprint of farming.

Reduction in Food Transportation Costs: Growing food in cities cuts down on long distance transportation, lowering costs and reducing carbon emissions.

Methods of Vertical and Urban Farming

Hydroponics: A soilless method where plants grow in nutrient-rich water solutions. It allows faster growth, higher yields, and requires 90% less water than traditional farming.

Aeroponics: Plants are grown without soil, with nutrient mist sprayed directly onto the roots. This technique improves oxygen absorption and speeds up growth.

Aquaponics: A combination of hydroponics and fish farming, where fish waste provides nutrients for plants, creating a self-sustaining ecosystem.

Container Farming: Shipping containers are repurposed into indoor farms with LED lighting, climate control, and hydroponic systems.

Rooftop and Greenhouse Farming: Utilizing urban rooftops to grow fruits, vegetables, and herbs, often with solar-powered irrigation systems.

Benefits of Vertical and Urban Farming

Maximized Space Utilization: Vertical farming stacks plants in multiple layers, producing more food per square meter than traditional farms. Urban farming makes use of vacant lots, rooftops, and indoor spaces.

Year-Round Crop Production: With controlled indoor environments, crops can be grown throughout the year, independent of seasonal changes, ensuring a steady food supply.

Reduced Water Consumption: Hydroponics and aeroponics use 90-95% less water than soil-based farming by recycling and reusing water efficiently.

Pesticide-Free Farming: Since these farms are in enclosed spaces, crops are less exposed to pests and diseases, reducing or eliminating the need for chemical pesticides.

Energy Efficiency and Sustainability: LED grow lights provide the optimal light spectrum for plants, reducing energy waste while maximizing photosynthesis. Some farms use solar or wind energy to further reduce their carbon footprint.

Job Creation and Community Engagement: Urban farms provide employment opportunities and promote community involvement, encouraging people to grow their own food and support local agriculture.

Fresher and Healthier Food: Locally grown food reaches consumers faster and fresher, reducing nutrient loss compared to produce that travels long distances.

Localized Production: Farming in cities brings food production closer to consumers, shortening supply chains and reducing transportation emissions.

Climate Change Mitigation: By reducing food miles and promoting efficient resource use, these farming methods help lower greenhouse gas emissions.

Challenges of Vertical and Urban Farming

High Initial Costs: Setting up vertical farms requires investments in technology, equipment, and climate control systems.

Energy Consumption: Indoor farming relies on artificial lighting and climate control, which can lead to high electricity usage if not powered by renewable sources.

Technical Knowledge Requirement: Farmers need training to manage hydroponic and aeroponic systems efficiently.

Limited Crop Variety: Leafy greens, herbs, and small vegetables thrive in vertical farms, but staple crops like wheat, rice, and corn are harder to cultivate indoors.

Regulatory and Zoning Issues: Some urban areas have restrictions on farming activities, making it difficult to establish large-scale urban farms.

Future of Vertical and Urban Farming

The demand for sustainable food production is growing, and technological advancements are making vertical and urban farming more efficient and affordable. Future trends include:

AI and IoT Integration: Smart sensors, AI-driven climate control, and automated irrigation will improve farming efficiency.

Use of Renewable Energy: Solar and wind energy will make urban farms more eco-friendly.

Expansion to New Crops: Innovations in plant genetics and growing techniques will allow a wider variety of crops to be grown indoors.

Urban Policy Support: Governments may introduce subsidies and incentives to promote local and sustainable agriculture.

Broader Adoption: The principles of vertical farming are expanding beyond cities to address food production in various climates and regions.

References

Ali, F. and Srivastava, C. (2017). Futuristic urbanism-An overview of vertical farming and urban agriculture for future cities in India. *International Journal of Advanced Research in Science, Engineering and Technology*, 4(4): 3767-3775.

Chatterjee, A., Debnath, S. and Pal, H. (2020). Implication of Urban Agriculture and Vertical Farming for Future Sustainability.

Benis, K. and Ferrão, P. (2018). Indoor farming mostly involves small-scale vertical gardens to large commercial facilities.

Eigenbrod, F. and Gruda, N. (2015). Urban farming → Potential, challenges and opportunities.

Benke, K. and Tomkins, B. (2017). Future food-production systems: Vertical farming and controlled-environment agriculture. Sustainability: Science, Practice and Policy. 13(1): 13-26.

Meenar, M. *et al.* (2017). Partnering with local government to identify and lease a vacant lot for urban agriculture.

Specht, K., Rosemarie, S., Hartmann, I., Freisinger, U. B., Sawicka, M., Werner, A., *et al*. (2014). Urban agriculture of the future: An overview of sustainability aspects of food production in and on buildings. *Agriculture and Human Values*, 31:33-51.

Zeeuw, H. D. (2011). Cities, climate change and urban agriculture. *Urban Agriculture Magazine*, 25: 39-42.

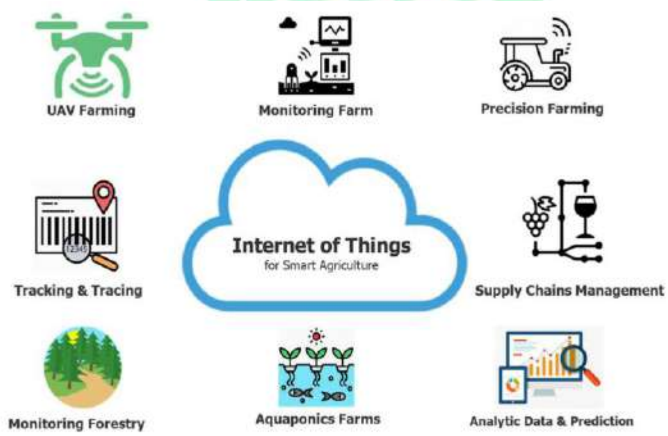
Zeeuw, H. D., Veenhuizen, R. V. and Dubbeling, M. (2011). The role of urban agriculture in building resilient cities in developing countries. *Journal of Agricultural Science*, 149: 153-163.

Smart Agriculture: Role of Internet of Things (IoTs)

Komal Gambhir

Introduction to IoTs

The term "Internet of Things" (IoT) describes a huge network of physical objects that are equipped with sensors, software, and other technologies built in to allow them to gather and share data with other systems and devices via internet. IoT is revolutionizing a variety of industries, from smart homes to precision agriculture by increasing the intelligence, responsiveness and efficiency of systems.



Applications of IoTs in Agriculture

Precision farming: Precision farming, often knows as precision agriculture, is any technique that improve accuracy and control of agricultural and livestock production. The utilization of IT, sensors, control systems, robotics, autonomous vehicles, automated hardware and so foth are all essential. Key technologies propelling the precision agricultural movement among manufacturers are mobile devices, high speed internet, and reasonably priced satellites.

Smart Irrigation: An emerging method for automating irrigation systems and reducing water consumption is the smart irrigation system. This method modifies irrigation as per weather and soil conditions. This system is more helpful in the areas with erratic rainfall, dry spells, or frequent drying out where the need for irrigation is most noticeable.

Crop Health Monitoring: One example of a technology advance in agriculture is the Crop Monitoring System. It makes use of the Internet of Things (IoT) and wireless sensor networks. Crop health monitoring is essential for spotting early indicators of illnesses, stress, nutrient shortages, and other issues that may have an impact on plant development and yield.

Livestock Monitoring: Data about the locations, health, and well-being of cattle can be gathered by large farm owners using wireless Internet of Things applications. By using this information, they are able to detect and remove diseased animals from the herd, stopping the spread of illness. Because IoT-based sensors allow ranchers to find their cattle, it also reduces labor costs. (i) The livestock's quality of life (QoL) and (ii) the state of the land where animals are raised are two invaluable tools for managing livestock production lines.

Smart Greenhouses: The technique of greenhouse farming aids in increasing the yield of crops, fruits, vegetables, etc. Greenhouses use a proportional

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control mechanism or manual intervention to regulate the environmental parameters. These approaches are less successful since manual intervention results in labor expenditures, energy loss, and output loss. The Internet of Things can be used to construct a smart greenhouse. This concept eliminates the need for manual intervention by automatically monitoring and controlling the environment.

Predictive analytics for smart farming: Predictive data analytics and precision agriculture are complementary. IoT and smart sensor technologies are a treasure trove of highly relevant real-time data, but data analytics also helps farmers make critical forecasts about yield volume, disease and infestation risks, and crop harvesting time. Because farming is so reliant on the weather, data analytics solutions assist make it easier to manage and more predictable.

Complete farm management systems: The so-called agricultural productivity management systems are an example of a more sophisticated approach to IoT goods in agriculture. They typically come with a number of sensors and IoT devices for agriculture set up on the property, along with a robust dashboard with built-in accounting and reporting tools and analytical capabilities.

Self-governing devices and robots: The topic of autonomous agricultural machinery has a bright future because to robotic advancements. Tractors, harvesters, and other equipment that can function without human supervision are already used by certain farms. These robots are capable of doing labor-intensive, difficult, and repetitive jobs.

Advantages of IoT in Agriculture

- ✓ Sensors monitor soil moisture, temperature, and nutrient levels.
- ✓ Enables targeted irrigation and fertilization, reducing waste.
- ✓ Farmers can track crop health, livestock movement, and equipment status remotely.
- ✓ Alerts for anomalies (e.g., pest infestation or water stress) allow quick intervention.
- ✓ To minimize water usage, smart irrigation systems use data.
- ✓ Fertilizer and pesticide application becomes more efficient and environmentally friendly.
- ✓ Automated systems reduce manual labor and increase operational efficiency.
- ✓ Drones and autonomous tractors speed up tasks like planting and spraying.
- ✓ Historical and real-time data help forecast yields, plan harvests, and manage supply chains.
- ✓ Reduced chemical runoff and better land management contribute to eco-friendly farming.
- ✓ Supports climate-smart agriculture practices.

Disadvantages of IoT in Agriculture

- ✓ Devices, infrastructure, and software can be expensive for small-scale farmers.
- ✓ Rural areas often lack reliable internet, limiting IoT functionality.
- ✓ Prior training is required for maintenance of IoT systems.
- ✓ Risk of underutilization if systems are too complex.

- ✓ It may be possible for sensitive agricultural data to be misused.
- ✓ Over-reliance may reduce traditional farming knowledge and resilience.
- ✓ System failures or outages can disrupt operations.
- ✓ Sensors and devices require regular calibration and updates.
- ✓ Environmental exposure can lead to wear and tear.

Role of IoTs in Agriculture

Through the use of technology, the internet of things (IoT) is transforming conventional farming methods in the agricultural sector by increasing sustainability, productivity, and efficiency. IoT devices are being developed on farms to gather real-time data on a variety of parameters, including soil conditions, weather patterns, crop growth, and machine performance. These devices include soil moisture sensors, weather monitors, crop monitors, and drones.

References

Ali, A., Hussain, T., Tantashutikun, N., Hussain, N. and Cocetta, G. (2023). Application of Smart Techniques, Internet of Things and Data Mining for Resource Use Efficient and Sustainable Crop Production. *Agriculture*, 13(2): 397.

Internet of Things in Agriculture: What is IoT and how is it implemented in agriculture? https://www.cropin.com/iot-in-agriculture/

Dhanaraju, M., Chenniappan, P., Ramalingam, K., Pazhanivelan, S., and Kaliaperumal, R. (2022). Smart Farming: Internet of Things (IoT)-Based Sustainable Agriculture. *Agriculture*, 12(10): 1745;

Applications of IoT in Agriculture - Making Agriculture Smarter, https://www.biz4intellia.com/blog/5-applications-of-iot-in-agriculture/

Post-registration Surveillance and Monitoring of Pesticides in India: A Comprehensive Scientific Review

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Abstract

The intensification of agricultural production has rendered pesticides indispensable for modern farming systems, yet their deployment carries inherent risks to human health, ecological integrity, and environmental quality. This comprehensive review examines the scientific methodologies and regulatory architecture underpinning post-registration surveillance systems for pesticides in India, with particular emphasis on the oversight mechanisms administered by the Central Insecticides Board and Registration Committee (CIBRC). We critically analyze the multifaceted surveillance framework encompassing market monitoring, residue analysis, adverse event documentation, quality assurance protocols, and periodic reassessment procedures. The synthesis reveals that robust post-registration monitoring constitutes an essential safeguard for ensuring continuous compliance with safety, efficacy, and environmental protection standards throughout a pesticide's commercial lifecycle.

Introduction

Background and Rationale: Contemporary agricultural systems have become increasingly dependent on synthetic pesticides to mitigate crop losses attributed to insect pests, plant pathogens, and weed competition. While these agrochemicals have demonstrably enhanced agricultural productivity and food security, their widespread application has engendered substantial concerns regarding potential adverse effects on human health, non-target organisms and ecosystem functioning. The dichotomy between agricultural benefit and environmental risk necessitates comprehensive regulatory frameworks that extend beyond initial product approval to encompass continuous post-market surveillance.

Scope and Objectives: The transition from controlled laboratory and field trial conditions to diverse real-world agricultural environments may reveal unforeseen consequences that were not apparent during pre-registration evaluation. Consequently, regulatory oversight must incorporate dynamic monitoring systems capable of detecting emerging risks, verifying product quality, and ensuring ongoing compliance with established safety parameters. This paper provides an in-depth examination of the scientific principles, methodological approaches, and institutional mechanisms that constitute India's post-registration pesticide surveillance system, with particular focus on the regulatory mandate of the Central Insecticides Board

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Legislative and Institutional Framework

Statutory Authority: The regulatory architecture governing pesticide post-registration monitoring in India derives its legal foundation from two principal legislative instruments: the Insecticides Act of 1968 and the Insecticides Rules of 1971. These statutes establish a comprehensive regulatory regime that encompasses the manufacture, distribution, sale, transport, and application of insecticidal substances. Under this legislative framework, the CIBRC functions as the apex regulatory authority responsible for ensuring that registered pesticide formulations maintain compliance with prescribed safety, efficacy, and environmental protection standards throughout their market presence.

Regulatory Objectives

Post-registration surveillance mechanisms serve multiple interconnected objectives that collectively enhance the safety profile of pesticide products in commercial circulation:

Efficacy Verification: Systematic assessment of pesticide performance under heterogeneous field conditions to confirm that products deliver the anticipated pest control outcomes specified in their registration dossiers. This encompasses evaluation across diverse agro-ecological zones, cropping systems, and pest pressure scenarios.

Toxicological Monitoring: Longitudinal surveillance to identify chronic or delayed health effects in exposed populations, including agricultural workers, rural communities, and consumers, that may not manifest during short-term pre-registration toxicity studies. This includes monitoring for cumulative toxicity, endocrine disruption, carcinogenicity, and reproductive effects.

Environmental Impact Assessment: Comprehensive evaluation of ecological consequences, including pesticide persistence in environmental matrices, bioaccumulation potential, effects on non-target organisms, and contribution to broader environmental concerns such as pollinator decline and aquatic ecosystem degradation.

Methodological Components of Post-Registration Surveillance

Market Surveillance and Compliance Verification: Market surveillance represents a foundational pillar of post-registration monitoring, designed to ensure that commercially available pesticide products conform to registered specifications and regulatory requirements.

Systematic Sampling Protocols: Regulatory authorities implement stratified random sampling strategies to collect pesticide specimens from diverse market channels, including retail agricultural input stores, wholesale distribution centers, and point-of-application sites at farming operations. These samples undergo rigorous analytical testing in accredited laboratories equipped with advanced instrumentation such as gas chromatography-mass spectrometry, high-performance liquid chromatography and inductively coupled plasma mass spectrometry to verify conformity of active ingredient concentrations with registered formulation specifications, absence of prohibited substances or unlisted inert ingredients, physical and chemical stability parameters, and presence of appropriate quality markers and authenticity indicators.

Label Integrity and Information Compliance: Comprehensive label audits ensure that pesticide packaging conveys accurate, complete, and legally mandated information. Regulatory inspectors verify compliance with labeling requirements encompass-sing precise identification of active ingredients with International Union of Pure and Applied Chemistry nomenclature, detailed usage instructions specifying application rates, timing, methods, and target pest spectrum, comprehensive safety precautions, enviro-nmental hazard warnings, first aid measures and emergency contact information for poisoning incidents, and batch identification codes enabling product traceability. Non-compliance with labeling standards constitutes grounds for enforcement action, including product seizure, mandatory corrective measures, or registration suspension.

Residue Monitoring Programs

Pesticide residue surveillance constitutes a critical component of public health protection and environmental stewardship, employing sophisticated analytical methodologies to quantify pesticide concentrations in agricultural commodities, environ-mental matrices, and biological specimens.

Food and Agricultural Commodity Monitoring: National residue monitoring programs implement risk-based sampling strategies targeting commode-ties with high consumption rates, intensive pesticide application histories, or documented compliance concerns. Analytical protocols employ multi-residue screening methods capable of detecting hundreds of pesticide compounds simultaneously, with quantific-ation limits typically in the parts-per-billion or parts-per-trillion range. Residue data are compared against Maximum Residue Limits established through dietary exposure assessments and toxicological reference values. The surveillance system enables detection of unauthorized pesticide applications on crops lacking registered uses, identification of excessive residue levels indicating non-compliance with good agricultural practices, assessment of cumulative dietary exposure from multiple pesticide residues, and evaluation of residue decline patterns and verification of pre-harvest interval adequacy.

Environmental Matrix Monitoring: Comprehe-nsive environmental monitoring programs assess pesticide fate and transport in soil, surface water, groundwater, and atmospheric compartments. This surveillance provides critical data on soil persistence through determination of pesticide half-lives under field conditions, assessment of degradation path-ways, and evaluation of potential for accumulation in agricultural soils. Aquatic contamination is assessed through systematic sampling of surface water bodies adjacent to agricultural areas, groundwater wells in pesticide-use zones, and drinking water sources to assess pesticide occurrence, concentration trends, and compliance with water quality standards. Atmospheric deposition monitoring focuses on pesticide volatilization, spray drift, and long-range atmospheric transport, particularly for semi-volatile compounds capable of undergoing atmospheric transport to non-target environments.

Ecological Exposure Assessment: Ecotoxicological surveillance programs monitor pesticide concentrations in biota, with emphasis on indicator species sensitive to pesticide exposure including aquatic organisms, pollinator species such as honeybees and native bees, soil fauna including earthworms and microarthropods essential for soil health, and avian species particularly raptors susceptible to secondary poisoning through consumption of contaminated prey. Biomonitoring data inform ecological risk assessments and support regulatory decisions regarding pesticide usage restrictions in sensitive habitats.

Adverse Event Surveillance and Pharmacovigilance

A comprehensive incident reporting system captures adverse effects manifesting under real-world use conditions, enabling detection of risks not identified during pre-registration testing.

Human Health Incident Reporting: Healthcare facilities, poison control centers, and occupational health services report suspected pesticide poisoning cases through a centralized database. Investigation protocols include clinical case characterization encompassing symptomatology, exposure circumstances and treatment outcomes, biological monitoring through analysis of blood, urine, or tissue samples for pesticide biomarkers, epidemiological investigation to identify patterns suggesting product-specific health risks, and assessment of exposure pathway, application practices, and protective measure compliance. Incident data undergo systematic causality assessment using standardized algorithms to determine the likelihood that observed health effects resulted from pesticide exposure.

Environmental Incident Documentation: Environmental surveillance captures reports of ecotoxicological incidents, including acute poisoning events affecting wildlife, domestic animals, or aquatic organisms, bee kills or other pollinator mortality incidents associated with pesticide applications, phytotoxicity to non-target vegetation including damage to adjacent crops or natural vegetation, and fish kills or benthic community impacts in aquatic ecosystems. Incident investigations employ forensic techniques including residue analysis of affected organisms, environmental sampling and reconstruction of exposure scenarios to establish causal relationships.

Investigation and Root Cause Analysis: When adverse events are reported, CIBRC initiates systematic investigations involving multidisciplinary expert teams encompassing toxicologists, environmental scientists, entomologists and agricultural specialists. Investigative procedures include on-site inspections to document use patterns, application equipment and environmental conditions, collection of environmental and biological samples for confirmatory residue analysis, interviews with applicators and affected parties, review of product stewardship programs and user training adequacy, and evaluation of whether incidents resulted from product defects, misuse, or inadequate risk mitigation measures. Investigation findings inform regulatory decisions regarding label amendments, use restrictions, or registration review.

Quality Assurance and Manufacturing Oversight

Continuous quality surveillance ensures consistency in pesticide manufacturing throughout a product's commercial lifecycle.

Manufacturing Facility Inspections: CIBRC conducts periodic compliance audits of pesticide manufacturing facilities to verify adherence to Good Manufacturing Practices. Inspection protocols evaluate raw material procurement and quality control procedures, manufacturing process controls including batch formulation procedures and in-process quality checks, quality control laboratory capabilities including analytical method validation and instrument calibration, storage conditions for raw materials and finished products, quality management systems including standard operating procedures and corrective action protocols, and environmental and worker safety compliance.

Batch Release Testing: Before commercial distribution, pesticide batches undergo certificate of analysis verification confirming active ingredient content within specification limits, absence of contaminants or impurities exceeding acceptable thresholds, physical properties including formulation stability and suspensibility, microbiological quality for water-based formulations, and packaging integrity and container compatibility.

Stability and Shelf-Life Monitoring: Accelerated stability studies and real-time storage testing verify that pesticide formulations maintain their efficacy and safety profiles throughout their claimed shelf life under representative storage conditions.

Periodic Re-evaluation and Registration Renewal

Scientific progress and emerging risk information necessitate systematic re-evaluation of registered pesticides at defined intervals.

Triggered Re-assessments: CIBRC initiates unscheduled re-evaluations when new toxicological data indicate previously unrecognized health risks, environmental monitoring reveals unacceptable persistence or ecological impacts, peer-reviewed scientific literature reports adverse effects not considered in original registration assessments, international regulatory actions by reference agencies signal emerging concerns, or post-market surveillance data indicate systematic compliance problems or efficacy failures.

Scheduled Re-registration: Pesticides undergo comprehensive registration renewal at intervals typically ranging from five to ten years. The re-registration process requires submission of updated scientific dossiers incorporating contemporary data requirements, reevaluation using current risk assessment methodologies and regulatory standards, assessment of availability and performance of alternative pest management strategies, comparative analysis of risk-benefit profiles against newer products or non-chemical alternatives, and evaluation of resistance development and efficacy sustainability. Re-registration decisions may result in continued approval, label modifications, use restrictions, or registration cancellation depending on risk-benefit assessment outcomes.

Regulatory Enforcement Mechanisms

Administrative Actions: The regulatory framework provides CIBRC with graduated enforcement authorities proportionate to the severity of violations or risks identified through surveillance activities.

Registration Suspension or Revocation: When post-market surveillance reveals serious safety concerns, manufacturing non-compliance, or systematic regulatory violations, CIBRC may suspend registrations pending corrective action or permanently revoke registration certificates. Suspension decisions consider severity and imminence of risks to human health or the environment, availability of safer alternative pest management tools, economic impacts on agricultural production systems, and feasibility of risk mitigation through label amendments or use restrictions.

Mandatory Product Recalls: Detection of adulterated, misbranded, or hazardous pesticide products triggers mandatory recall procedures requiring immediate cessation of distribution and sale, public notification through regulatory announcements and media communications, systematic retrieval of products from distribution channels, secure storage or disposal of recalled products under regulatory supervision, and corrective action plans to prevent recurrence.

Use Restriction Modifications: Emerging risk information may necessitate amendments to registered use patterns without complete product withdrawal. Restriction modifications include prohibition of applications in sensitive environments, temporal restrictions to avoid exposure of non-target organisms during vulnerable life stages, reduction of maximum application rates or frequency, requirements for specialized application equipment or techniques, mandatory buffer zones or drift-reduction measures, and enhanced personal protective equipment requirements.

Compliance Incentives and Stakeholder Engagement

Effective surveillance systems combine enforcement mechanisms with proactive engagement strategies including training programs for pesticide dealers and applicators, stewardship initiatives promoting responsible pesticide use practices, public awareness campaigns regarding safe handling and environmental protection, mechanisms for industry self-reporting of adverse events and quality issues, and stakeholder consultation in development of revised regulatory standards.

Challenges and Future Directions

Current Limitations: Despite comprehensive regulatory frameworks, several challenges constrain the effectiveness of post-registration surveillance. Resource constraints limit analytical capacity, personnel, and funding which restrict the scope and frequency of monitoring activities. Geographic coverage remains inadequate in remote agricultural regions or for minor crops. Analytical complexity increases as expanding pesticide portfolios and complex formulations require sophisticated analytical capabilities. Data integration is hindered by fragmented information systems that prevent synthesis of surveillance data across monitoring domains. Emerging contaminants including novel pesticide classes and transformation products may elude existing analytical methods.

Opportunities for Enhancement: Strategic priorities for strengthening post-registration surveillance include technological innovation through implementation of rapid screening technologies, biosensors, and high-resolution mass spectrometry to expand monitoring capacity. Risk-based prioritization involves deployment of sophisticated risk assessment models to optimize resource allocation toward highest-priority surveillance targets. Digital infrastructure development focuses on integrated data management systems enabling real-time data sharing and trend analysis. International harmonization aligns surveillance protocols with international standards facilitating data comparability and regulatory cooperation. Citizen science integration engages agricultural communities in adverse event reporting and environmental monitoring.

Conclusions

Post-registration surveillance and monitoring constitute indispensable components of the pesticide regulatory continuum in India, bridging the gap between controlled pre-market evaluation and heterogeneous real-world application conditions. The multifaceted surveillance architecture administered by CIBRC, encompassing market compliance verification, residue monitoring, adverse event surveillance, quality assurance, and periodic re-evaluation, provides essential safeguards for human health, ecological integrity and environ-mental quality. The dynamic nature of agricultural systems, pest populations and scientific under-standing necessitates adaptive regulatory frameworks capable of responding to emerging risks while facilitating agricultural innovation. Contin-uous enhancement of surveillance methodologies, analytical capabilities, and institutional capacity remains essential for ensuring that pesticide deployment continues to support agricultural productivity without compromising public health or environmental sustainability. Future strengthening of post-registration monitoring systems will require sustained investment in analytical infrastructure, workforce development, technological innovation and stakeholder collaboration. Such investments represent not merely regulatory obligations but strategic imperatives for sustainable agricultural development and environmental stewardship in India's evolving agricultural landscape.

References

Insecticides Act. (1968). Ministry of Agriculture and Farmers Welfare, Government of India.

Insecticides Rules. (1971). Ministry of Agriculture and Farmers Welfare, Government of India.

CIBRC Guidelines for Pesticide Post-Registration Monitoring. (2024). Ministry of Agriculture and Farmers Welfare, Government of India.

Exotic Vegetables: Role for Nutritional Security in the Indian Context

Pankaj Kumar Ray

Introduction

India, with its vast and diverse population, continues to face significant challenges in achieving comprehensive nutritional security. According to the Global Hunger Index and National Family Health Survey (NFHS-5), malnutrition both under nutrition and micronutrient deficiency remains prevalent across various strata of society, particularly in children, women, and elderly populations. While government programs such as the Integrated Child Development Services (ICDS), Mid-Day Meal Scheme, and Poshan Abhiyaan have made commendable progress, the current food basket of the Indian population still lacks diversity, especially in terms of micronutrient-rich vegetables (Rao *et al*., 2023). Amidst this background, exotic vegetables have emerged as a potential solution to complement traditional Indian diets and bridge the nutritional gap. These vegetables, often non-native to India, are cultivated either under controlled conditions or in suitable agro-climatic zones. They include broccoli, red and yellow capsicum, lettuce, cherry tomato, kale, zucchini, celery, bok choy, asparagus, leek, and Chinese cabbage, among others. Despite being relatively new to Indian markets, their nutrient-rich profiles and expanding demand present promising opportunities for both consumer health and agricultural diversification.

Nutritional Significance of Exotic Vegetables

Exotic vegetables are known for their high concentration of essential vitamins, minerals, phyto-chemicals, and antioxidants that are often deficient in staple cereal-based Indian diets. For instance, broccoli is a powerhouse of vitamin C, vitamin K, calcium, potassium, folate, and dietary fiber, and contains potent antioxidants like sulforaphane and glucosinolates, which have anti-carcinogenic properties (Verma *et al*., 2020). Similarly, kale, one of the most nutrient-dense vegetables, is rich in iron, vitamin A, lutein, and omega-3 fatty acids, which are essential for preventing anemia, improving vision, and reducing inflammation (Singh *et al*., 2021).

Colored capsicums (red, yellow, and orange bell peppers) are particularly high in carotenoids, vitamin C, and flavonoids, all of which enhance immunity and reduce oxidative stress (Patel *et al*., 2019). Lettuce and bok choy, with their low calorie and high fiber content, are suitable for weight management and diabetic-friendly diets, offering an ideal alternative for health-conscious individuals (Kumar *et al*., 2022).

Furthermore, exotic leafy vegetables like Swiss chard and romaine lettuce provide high levels of vitamin K, which is essential for blood clotting and bone health. The inclusion of asparagus, known for its folate and diuretic properties, can benefit

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pregnant women and individuals with cardiovascular disorders. Such nutritional properties make exotic vegetables a valuable addition to everyday meals, especially in urban settings where dietary patterns are rapidly shifting towards processed and fast food (Chatterjee and Saravanan, 2020).

Demand Dynamics and Market Growth in India

Over the past decade, there has been a notable increase in consumer demand for exotic vegetables in India, driven by several factors: globalization, increased travel, the proliferation of international cuisines in urban centers, awareness about healthy eating, and the growth of the middle class. Supermarkets, organic food outlets, online grocery platforms, and upscale restaurants have played a key role in creating market visibility and demand pull for these vegetables (Singh *et al*., 2021).

In metropolitan cities like Delhi, Bengaluru, Mumbai, and Hyderabad, weekly consumption of exotic vegetables such as broccoli, zucchini, and lettuce is no longer limited to a niche population but has become part of the regular diet for health-conscious households. This rising demand has created opportunities for farmers, especially those near urban clusters, to diversify from conventional crops to high-value exotic horticulture, supported by protected cultivation practices like greenhouses, polyhouses, net houses, and hydroponics (Sharma *et al*., 2018).

Role in Public Health and Nutritional Security

One of the most crucial roles of exotic vegetables is their potential to address micronutrient malnutrition, or "hidden hunger," which affects over 30% of the Indian population, especially in children under five and women of reproductive age (Rao *et al.*, 2023). These vegetables, when integrated into school feeding programs, urban nutrition missions, and hospital diets, can significantly improve dietary diversity. Moreover, consumption of exotic vegetables can help in the prevention and management of non-communicable diseases (NCDs) such as obesity, hypertension, cardiovascular diseases, and diabetes, which are on the rise in both urban and rural India (Kumar *et al.*, 2022). Their low glycemic index, high fiber, and anti-inflammatory properties support metabolic health and can contribute to India's goal of reducing NCD-related morbidity. Awareness campaigns, cooking demonstrations, and recipe innovation involving exotic vegetables can further promote their acceptability in traditional Indian diets, especially when coupled with nutrition education in schools and communities (Patel *et al*., 2019).

Conclusion

In conclusion, exotic vegetables offer a unique opportunity to strengthen nutritional security in India by enriching diets with vital nutrients, supporting better health outcomes, and creating new income avenues for farmers. While their cultivation and consumption are currently limited to certain pockets, strategic efforts can make them accessible, affordable, and acceptable across wider sections of the population. As India aims to meet its Sustainable Development Goals (SDGs), particularly SDG 2

(Zero Hunger) and SDG 3 (Good Health and Well-being), the promotion of exotic vegetables can be a transformative step in achieving food and nutritional well-being for all.

References

Chatterjee, R. and Saravanan, R. (2020). Protected cultivation of exotic vegetables: An emerging opportunity for smallholder farmers. *Journal of Horticultural Science and Research*, 9(1): 34-42.

Kumar, V., Mishra, A. and Devi, S. (2022). Leafy exotic vegetables and their dietary relevance in non-communicable diseases management. *Nutrition and Health Review*, 11(2): 85-93.

Patel, M., Singh, P. and Yadav, R. (2019). Nutritional and therapeutic potential of colored capsicum: A review. *International Journal of Food and Nutritional Sciences*, 8(3): 41-47.

Rao, D. S., Meena, R. K. and Roy, S. (2023). Mainstreaming exotic vegetables in Indian nutritional programs: A policy perspective. *Indian Journal of Agricultural Economics*, 78(1): 113-122.

Sharma, H., Bhatt, R. and Negi, A. (2018). Scope of exotic vegetable cultivation in Himalayan states of India. *Indian Horticulture Journal*, 7(2): 64-71.

Singh, A., Chauhan, N. and Srivastava, R. (2021). Exotic vegetables: A new avenue for nutritional security and farm profitability in India. *Agricultural Innovations*, 14(4): 25-30.

Verma, S., Gupta, A. and Rathi, P. (2020). Health benefits of cruciferous vegetables and their bioactive compounds. *Functional Foods Research*, 5(1): 50-58.

Farmers' Demand for Legal MSP: Stakes for Indian Agriculture

Kaustubh Kadam, Anjali Dahatonde and Arundhati Lawand

What is MSP?

The Minimum Support Price (MSP) is the floor price set annually by the government for certain government-notified crops, aiming to protect farmers from steep price falls in the open market. MSP helps ensure farmers receive a minimum payoff for their produce, particularly staples like wheat and rice, which the government procures to create buffer stocks for food security programs. In addition to MSP, there are other instruments like bonuses and direct payments which supplement farmer incomes. However, MSP remains the primary tool to provide price assurance, especially during periods of market volatility and unpredictable weather. While MSP is declared, procurement at MSP is only guaranteed for selected crops in specific areas, which has led to farmers pressing for a legal guarantee covering all crops and regions.

At a glance: Recent MSP facts

The government's rice and wheat procurement rose significantly in the 2024-25 season, with rice procurement estimated to surpass last year's figures and wheat procurement showing around a 44% increase early in the season. Farmer protests beginning February 2024 have prominently featured the demand for a legal MSP covering all crops among their core issues. In some states, farmers report market prices falling below MSP due to gaps in procurement implementation, leaving many unable to sell at the government-declared price.

Government stance: The central government maintains that MSP is a policy tool and that procurement ensures food security. However, it has been cautious in making MSP a legally binding right. Officials cite concerns about the fiscal burden this might impose and the logistical challenges of scaling procurement to cover all crops nationwide. The government often attempts to balance calls for legal MSP with measures like procurement bonuses and direct support schemes to appease protesting farmers. Press releases from the Ministry of Agriculture emphasize that while MSP support exists, enforcing a blanket legal guarantee would require substantial expansion of storage, supply chain infrastructure and budget allocations. Moreover, authorities warn that compulsory purchases at MSP could distort market dynamics and may encourage overproduction of certain crops.

What experts say for legal MSP: Supporters argue that legalising MSP provides farmers with much-needed price certainty, especially smallholders vulnerable to market crashes. It acts as a safety net amid rising input costs and agricultural uncertainties, aiming to prevent distress sales and the cycle of indebtedness affecting millions. Farmers' unions and activists highlight MSP as a fundamental right.

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“Legal guarantee on MSP is the key demand,” says Via Campesina, a prominent advocacy group.

Against legal MSP: Economists and policymakers caution about the fiscal implications of legally enforcing MSP for all notified crops. There is concern that the state might be forced to purchase vast quantities of produce, leading to excessive government spending and storage challenges. Economist Ashok Gulati notes that a blanket buy-back model may be “impossible” without causing market distortions and inefficiencies.

“Legal MSP is the bare minimum but the consequences of a blanket buy-back demand real policy solutions,” Gulati states, emphasizing the need for more nuanced approaches.

Human angle and case studies: Ram Singh, a smallholder from Punjab, recounts selling mustard below MSP in a village where procurement was absent last year. “Without buyers from the government, we had no choice but to accept low prices,” he says.

In contrast, in Haryana, officials credit procurement bonuses for encouraging farmers to sell to government agencies during the last season, helping stabilize incomes. Meanwhile, a grain trader from Madhya Pradesh points to wide state-level variation in procurement policies, which affects local prices and farmer trust in the system. These ground realities illustrate how the promise of MSP varies widely across regions, affecting farmers unevenly based on local implementation.

Policy options and trade-offs: Policy experts suggest alternatives to a blanket legal MSP, such as targeted deficiency payments that compensate farmers only when market prices fall below MSP, crop insurance schemes, enhanced procurement coverage in underserved areas, and direct income support measures. These options aim to achieve price security while managing fiscal and logistical challenges. Legal MSP can be a short-term measure for farmer relief, but long-term agricultural sustainability may require diversified policy tools, including improved market access, supply chain efficiency, and risk management strategies.

Conclusion

The debate over legalising MSP is more than a question of policy it speaks to the heart of India’s agricultural future. With farmers’ livelihoods at stake, the government’s balancing act between assurances and economic feasibility continues. Can India design a system that protects farmers without bankrupting the state and distorting markets? That is the pressing question for policymakers and citizens alike.

Role of Nanotechnology in Fruit Crops

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Abstract

Nanotechnology offers innovative and sustainable solutions to enhance fruit crop production, quality, and shelf life. It enables precise nutrient delivery through nanofertilizers, targeted pest and disease control via nanopesticides, and controlled agrochemical release. Nanocoatings and nanocomposite packaging help maintain post-harvest freshness by reducing microbial contamination and regulating gas exchange. Additionally, nanotechnology improves micronutrient bioavailability, enriching the nutritional value of fruits. Overall, it addresses modern agricultural challenges, boosting productivity, resilience, and food security in an environmentally sustainable manner.

Introduction

The growing global demand for nutritious fruit crops has intensified the need to enhance yield and quality. Conventional methods like breeding, chemical inputs, and improved cultivation often fall short in addressing challenges such as climate change and soil degradation. Nanotechnology offers innovative solutions by manipulating materials at the nanoscale (1-100 nm) to improve agricultural efficiency. Applications include smart nutrient delivery, precise pest and disease management, and enhanced postharvest quality (Zafar *et al.*, 2020; Razzaq *et al*., 2023). Nano-fertilizers boost nutrient uptake and plant growth (Naderi and Danesh-Shahraki, 2013), while nanopesticides enable targeted control, reducing chemical use and resistance risks (Kah *et al.*, 2013), thus promoting sustainable fruit crop production (Shoukat *et al.*, 2024; Zafar *et al.*, 2024).

Mechanism of Uptake: Nano-fertilizers are absorbed by plants through roots or leaves, with uptake influenced by particle size, shape, and surface properties. The plant cell wall, with a pore limit of 5–20 nm, restricts larger particles, though surface modification can enhance entry. Uptake occurs via ion channels, endocytosis, membrane transporters, or root exudate interactions. Nano-carriers retain nutrients near roots, minimizing leaching and improving soil mobility. In foliar application, nanoparticles penetrate through stomata or the cuticle, which restricts particles under 5 nm. Once inside, they move via apoplastic or symplastic pathways, ensuring efficient nutrient transport and improved plant growth and productivity.

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Nanocoating: Nanocoating applies an ultra-thin layer (<100 nm) on surfaces to enhance protection and functionality in agriculture. It acts as a barrier against contaminants and stress, reducing water loss and slowing degradation. Food-grade wax nanocoatings on fruits like citrus, apples, and tomatoes preserve freshness, improve appearance, and extend shelf life during storage and transport.

Nanotechnology for fruit crop quality enhancement enhancing nutritional value: Nanotechnology enhances the nutritional quality of fruit crops by improving nutrient absorption and utilization. Nanofertilizers, superior to conventional types, ensure controlled and sustained release of essential nutrients like nitrogen, phosphorus, and potassium, boosting plant metabolism and enriching fruits with vitamins, minerals, and antioxidants (Shoukat *et al*., 2024). Additionally, nanoparticle-based delivery of micronutrients such as iron, zinc, and selenium increases their solubility and uptake, leading to higher nutrient accumulation in fruits (Khot *et al.*, 2012). This advancement not only enhances fruit nutritional value but also helps address micronutrient deficiencies, contributing to improved public health and sustainable agriculture.

Enhancing Shelf-Life and Post-Harvest Quality: The post-harvest stage is vital for maintaining fruit quality and market value, as fruits are highly susceptible to spoilage and microbial contamination. Nanotechnology offers innovative solutions to extend shelf life and preserve quality through advanced packaging and coatings. Nanocomposite packaging materials, incorporating nanoparticles, improve gas barrier properties and reduce respiration and ethylene production, maintaining freshness and texture (De Azeredo, 2009). Additionally, anti-microbial coatings containing silver, zinc oxide, or titanium dioxide nanoparticles inhibit bacterial and fungal growth, ensuring food safety (Emamifar *et al*., 2010). These nanotechnological advancements minimize post-harvest losses and enhance fruit marketability and storage stability.

Disease Resistance and Pest Management: Fruit crops are highly susceptible to pests and diseases, leading to reduced yield and quality. Conventional chemical pesticides often lose effectiveness over time and contribute to resistance development. Nanotechnology offers sustainable solutions through nanopesticides formulations using nanoparticles to enhance solubility, stability, and targeted delivery of active ingredients (Zafar *et al*., 2022; Kah *et al*., 2013). These nanopesticides enable precise control of pests and pathogens, increasing efficacy while reducing chemical usage and environmental harm.

Nanofertilizers for Optimized Nutrient Delivery: Conventional fertilizers often show low efficiency due to nutrient losses through leaching and volatilization, leading to reduced crop yield and environmental pollution. Nanofertilizers address this challenge by enabling controlled and sustained nutrient release at the nanoscale. They deliver essential nutrients like nitrogen, phosphorus, and potassium in sync with crop growth stages, enhancing nutrient uptake, maximizing productivity and minimizing environmental impact (Liu and Lal, 2015; Yadav *et al.*, 2023).

Nanoscale Delivery Systems for Agrochemicals: Effective delivery of agrochemicals is vital for boosting fruit crop yields while minimizing environmental harm. Conventional methods often waste chemicals and reduce efficiency. Nanotechnology overcomes these issues through nanoscale delivery systems that encapsulate active ingredients, protect them from degradation, and release them precisely at target sites (Kah *et al.*, 2013). This targeted approach lowers chemical use, costs, and pollution.

Conclusion

Nanotechnology offers innovative solutions to enhance fruit crop production by improving yield, nutritional quality, and post-harvest longevity. Through nanofertilizers, it ensures efficient nutrient delivery, minimizing losses and environmental impact while promoting healthier fruits. Nanoscale agrochemical systems provide targeted pest and disease control, reducing chemical use and resistance risks. In post-harvest management, nanocoatings and advanced packaging extend shelf life by preventing microbial contamination and regulating respiration. Additionally, nanoparticles enhance the bioavailability of essential nutrients, contributing to better fruit quality and human health.

References

Liu, R. and Lal, R. (2015). Potentials of engineered nanoparticles as fertilizers for increasing agronomic productions. *Science of the Total Environment*, 514: 131-139.

Azam, A., Ahmed, A. S., Oves, M., Khan, M. S., Habib, S. S. and Memic, A. (2022). Anti-microbial activity of metal oxide nano-particles against Gram-positive and Gram-negative bacteria: A comparative study. *International Journal of Nanomedicine*, 7: 6003-6009.

De Azeredo, H. M. C. (2009). Nanocomposites for food packaging applications. *Food Research International*, 42(9): 1240-1253.

Emamifar, A., Kadivar, M., Shahedi, M. and Soleimanian-Zad, S. (2010). Evaluation of nanocomposite packaging containing Ag and ZnO on the shelf life of fresh orange juice. *Food Chemistry*, 120(1): 193-200.

Gogos, A., Knauer, K. and Bucheli, T. D. (2012). Nanomaterials in plant protection and fertilization: Current state, foreseen applications, and research priorities. *Journal of Agricultural and Food Chemistry*, 60(39): 9781-9792.

Kah, M., Beulke, S., Tiede, K. and Hofmann, T. (2013). Nanopesticides: State of knowledge, environmental fate, and exposure modelling. *Critical Reviews in Environmental Science and Technology*, 43(16): 1823-1867.

Khot, L. R., Sankaran, S., Maja, J. M., Ehsani, R. and Schuster, E. W. (2012). Applications of nanomaterials in agricultural production and crop protection: A review. *Crop Protection*, 35: 64-70.

Naderi, M. R. and Danesh-Shahraki, A. (2013).

Nanofertilizers and their roles in sustainable agriculture. *International Journal of Agriculture and Crop Sciences*, 5(19): 2229-2232.

Razzaq, A., Khan, S. U., Farooq, W., Yousaf, S. and Mahmood, N. (2023). Role of nanotechnology in enhancing crop productivity and stress tolerance. *Frontiers in Plant Science*, 14: 112-126.

Shoukat, A., Bhat, J. A., Jan, R. and Wani, S. H. (2024). Nanotechnology for climate change mitigation: Enhancing plant growth and sustainable agriculture. *Journal of Plant Nutrition and Soil Science*, 187(2): 145-157.

Yadav, S., Singh, A. and Kumar, P. (2023). Nanofertilizers for sustainable nutrient management and crop productivity: A review. *Environmental Nanotechnology, Monitoring & Management*, 20: 100873.

Zafar, M., Shahid, M., Ditta, A. and Imran, M. (2024). Nanotechnology applications in fruit production: Opportunities and challenges. *Agricultural Nanotechnology Journal*, 2(1): 15-28.

Unlocking the Hidden Treasure: Evaluating Genetic Diversity in Traditional Landraces through Morphological Traits

Chelsi, Deepak Gupta and Ghanprakash Ghoretha

Abstract

Traditional landraces, developed and maintained by farmers over generations, are invaluable sources of genetic diversity. They possess unique adaptive traits that contribute to yield stability, stress tolerance and nutritional quality under diverse environmental conditions. However, the increasing dependence on high yielding varieties has led to the gradual erosion of these genetic resources. Assessing genetic diversity in landraces through morphological traits offers a practical and cost-effective approach to identifying superior genotypes for breeding and conservation. Morphological characterization, based on visible plant features such as plant height, branching pattern, flowering time, seed characteristics and yield, provides essential baseline information for evaluating variability. Such studies help in selecting genetically diverse parents for hybridization, discovering rare traits for stress tolerance and guiding conservation strategies. Promoting the use and preservation of traditional landraces is essential to strengthen future breeding programs and ensure sustainable agricultural development in the face of climate change.

India is home to an incredible diversity of traditional crop varieties that have evolved over centuries through farmers' selection and natural adaptation. These locally adapted varieties, known as landraces, are reservoirs of valuable genes for yield stability, stress tolerance and nutritional quality. However, with the widespread adoption of modern high yielding varieties, many landraces are disappearing from our farmlands. Understanding and conserving this diversity is vital to ensure food and nutritional security in the face of climate change. Evaluating the genetic diversity present in traditional landraces using morphological traits offers a simple yet powerful approach for identifying superior genotypes for future crop improvement.

What are the Traditional Landraces?

Landraces are farmer developed varieties maintained over generations under specific local environments. They exhibit a wide range of variability in morphological and physiological traits such as plant height, flowering time, pod or ear size and grain color. These varieties may not always yield the highest under modern conditions, but they possess unique adaptive features resistance to drought, tolerance to heat, or natural defense against local pests and diseases that make them invaluable for

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sustainable agriculture.

Why Study Genetic Diversity?

Genetic diversity is the backbone of every successful crop improvement program. It represents the total variation present in the genetic makeup of a species the raw material that plant breeders rely on to develop better, stronger and more productive varieties. Without sufficient diversity, the scope for genetic improvement becomes extremely limited. In traditional landraces, this diversity is naturally rich because they have evolved over centuries under varied climatic and soil conditions, often exposed to diseases, pests and environmental challenges. By studying and understanding this variation, breeders can make informed decisions for future breeding strategies.

Identifying potential parents for hybridization programs: The first step in any hybridization program is to select genetically diverse parents. When two distinct landraces are crossed, their contrasting genes combine to produce offspring with greater variability-a phenomenon that can lead to hybrid vigor or heterosis. Evaluating diversity helps breeders identify those landraces that are most genetically distant and, therefore, likely to produce superior recombinants.

Detecting unique and rare traits for stress tolerance: Many traditional landraces possess special traits that modern cultivars have lost such as tolerance to drought, salinity and high temperatures. Some even carry resistance genes against region specific diseases and pests. By analyzing genetic diversity, researchers can pinpoint and preserve these rare and valuable traits, using them as a source of genes for developing climate resilient and disease resistant varieties.

Guiding conservation efforts for valuable genetic resources: Understanding diversity helps in setting priorities for germplasm conservation. Landraces that show wide genetic differences from others can be given special attention for in situ (on-farm) or ex situ (gene bank) conservation. This ensures that the broad genetic base of the species is maintained for future breeding and research needs.

Reducing vulnerability to diseases and environmental stress: When a large area is planted with a single, uniform variety, the entire crop becomes vulnerable to a new disease, pest or weather stress as seen during the Irish potato famine and other historical epidemics. Maintaining genetic diversity acts as a biological insurance, reducing the risk of widespread crop failure and ensuring long-term agricultural stability.

In simple terms, studying genetic diversity ensures that we do not put all our “genetic eggs in one basket.” It keeps the crop gene pool healthy, adaptable, and ready to face future challenges. By valuing diversity today, we safeguard the resilience and sustainability of tomorrow’s agriculture.

Using Morphological Traits: The Classical Approach

Although modern breeding programs increasingly rely on molecular markers and genomic tools to assess genetic variation, morphological characterization continues to be the first and most practical step in evaluating genetic diversity especially in traditional breeding programs and resource-limited research settings.

Morphological traits are those visible and measurable plant features that reflect the combined expression of a plant's genotype and its interaction with the environment. These characteristics are easy to observe, require no sophisticated equipment and provide an immediate understanding of the variability present among genotypes.

Key Morphological Traits in Diversity Studies

In most crops, breeders focus on a set of core morphological traits that have direct or indirect influence on growth, adaptability and yield potential. Common examples include:

Plant height and growth habit: These traits are vital for understanding plant architecture. Variation in height and branching pattern indicates differences in adaptation and potential biomass. For instance, tall landraces may perform better under rainfed conditions, while shorter ones are preferred for mechanical harvesting.

Number of branches and pods per plant: These yield related traits often show large variation among landraces. A higher number of branches and pods generally contributes to greater seed yield, making them important selection criteria in self-pollinated crops like mungbean or cowpea.

Seed size, shape and color: These are among the most distinguishing features of traditional landraces. Farmers often select seeds based on their physical appearance, leading to tremendous diversity. Such traits are also linked to consumer preference, market value and sometimes nutritional quality.

Days to flowering and maturity: These traits determine the crop's duration and adaptability to different agro-climatic conditions. Early-maturing types escape terminal drought or heat, whereas late-maturing ones can produce higher yields under favorable conditions.

Grain or seed yield per plant: The ultimate trait of economic importance, yield integrates the effects of many morphological and physiological attributes. Differences in yield performance among landraces reflect their genetic potential under given environments.

How Morphological Traits Help in Diversity Analysis

Once data on these traits are recorded, scientists use statistical tools to quantify the extent of variation among landraces. Techniques such as Mahalanobis D^2 statistics, cluster analysis and principal component analysis (PCA) help group landraces into different clusters based on similarity or genetic distance.

- ✓ Landraces falling in the same cluster are genetically more similar.
- ✓ Those in different clusters are genetically diverse and can be chosen as parents for hybridization to create new recombinations.

This approach helps breeders identify promising combinations that are likely to produce transgressive segregants or hybrids with superior yield and adaptability.

Advantages of the Morphological Approach

Cost-effective: Requires only basic field facilities and no specialized laboratory setup.

Practical for farmers and students: Easy to observe and understand, even without advanced training.

Foundation for molecular work: Provides essential baseline data before using molecular or biochemical markers.

Useful for on-farm selection: Farmers can identify superior plants based on visible traits and maintain them for the next season.

Limitations and the Way Forward

While morphological traits are invaluable, they can be influenced by the environment meaning that expression of certain traits may vary under different growing conditions. Hence, combining morphological data with molecular and physio-logical characterization offers a more accurate picture of genetic diversity. Nevertheless, morpho-logical evaluation remains the cornerstone of traditional plant breeding, helping researchers and farmers alike recognize and preserve the rich diversity present in our traditional landraces.

Key Messages for Farmers

Traditional varieties are treasure houses of valuable genes: These landraces often possess natural tolerance to drought, heat, and diseases, making them excellent choices for climate resilient farming.

Visible (morphological) differences help identify region-specific types: Traits like plant height, seed color, pod length and maturity period can help farmers and scientists recognize the most suitable varieties for their local conditions.

Conserving local landraces supports long-term sustainability: Maintaining traditional varieties ensures a steady supply of diverse genes that can be used for future crop improvement and food security.

Farmers play a vital role in preserving diversity: By saving, exchanging and cultivating traditional seeds every season, farmers become guardians of our agricultural heritage.

Diversity in the field means security on the farm: Growing multiple traditional types together reduces the risk of total crop loss from pest outbreaks or weather extremes.

Conclusion

Traditional landraces represent the living heritage of our agricultural past and the foundation for future food security. They harbor a wide range of genetic variation that has evolved naturally under diverse environmental conditions and farmer selection. Evaluating genetic diversity among these landraces using morphological traits remains a simple, economical, and effective approach to uncovering valuable genetic potential. Such diversity studies enable breeders to identify distinct and promising genotypes for use in hybridization and improvement programs. In the current era of climate variability, declining soil fertility and emerging pest challenges, conserving and utilizing these traditional varieties is more important than ever.

Integrating morphological evaluation with modern molecular tools will further enhance our understanding of diversity and accelerate the development of climate-resilient, high-yielding cultivars. Preserving our landraces is not only an act of conservation but also a strategic investment in the sustainability and resilience of Indian agriculture. By valuing and protecting these genetic treasures today, we secure the foundation for a productive and food-secure tomorrow.

Plant Vaccines: The Future of Disease Prevention Grown in Plants

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Introduction

The global burden of infectious diseases remains a significant challenge, with millions of lives lost annually to pathogens such as hepatitis B virus (HBV), human immunodeficiency virus (HIV), and severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2). Traditional vaccine production methods, which often rely on mammalian or egg-based systems, face limitations including high costs, complex purification processes, and the need for cold-chain storage. These constraints are particularly pronounced in low-resource settings, where access to vaccines is limited. In response, plant-based vaccine production, or molecular pharming, has emerged as a promising alternative, offering a scalable, cost-effective, and sustainable approach to immunization. By leveraging plants as bioreactors to produce antigenic proteins, "plant vaccines" could revolutionize disease prevention, particularly for emerging pandemics and neglected tropical diseases.

The Science of Plant-Based Vaccines

Plant-based vaccines involve the genetic engineering of plants to express specific antigens that elicit an immune response in humans or animals. The process begins with the introduction of a gene encoding a pathogen-specific protein into the plant genome, typically using one of two methods: stable transformation or transient expression.

Stable Transformation: In stable transformation, the antigen-encoding gene is integrated into the plant's nuclear or chloroplast genome, creating transgenic plants that pass the gene to their progeny. This method, often facilitated by *Agrobacterium tumefaciens* mediated gene transfer or biolistic bombardment, ensures consistent antigen production across generations. For example, transgenic tobacco and lettuce have been engineered to express hepatitis B surface antigen (HBsAg), demonstrating immunogenic potential in preclinical studies.

Transient Expression: Transient expression, uses plant viral vectors or agroinfiltration to temporarily express the antigen without altering the plant's genome. This approach is faster, often producing antigens within days, and is particularly suited for rapid response to outbreaks. The MagnICON system, a transient expression platform, has been used to produce SARS-CoV-2 spike proteins in tobacco, showcasing the speed and scalability of this method.

Antigen Delivery: Edible Vaccines: One of the most innovative aspects of plant-based vaccines is

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the potential for oral delivery through edible plants. Unlike injectable vaccines, edible vaccines eliminate the need for needles, reducing administration costs and improving patient compliance, especially in pediatric populations. Plants such as potatoes, tomatoes, and rice have been explored as vehicles for edible vaccines. For instance, transgenic rice expressing the VP2 protein of infectious bursal disease virus has induced protective immunity in chickens, highlighting the feasibility of oral immunization.

Advantages of plant-based vaccine production

Cost-Effectiveness: The production of vaccines in plants is significantly cheaper than in mammalian cells or eggs. Plants require minimal infrastructure, relying on standard agricultural practices rather than expensive bioreactors. For example, it has been estimated that the hepatitis B antigen needed to vaccinate the entire population of China could be grown on a 40-acre plot, with a single dose costing approximately 0.43 cents. This affordability is critical for addressing vaccine inequity in developing countries.

Scalability: Plants can be cultivated on a large scale, allowing for rapid production of vaccines in response to pandemics. Medicago, a Canadian biotechnology company, has demonstrated this scalability by producing a quadrivalent influenza vaccine using tobacco, with the capacity to generate up to 50 million doses annually. The ability to scale production using greenhouses or open fields makes plant-based systems ideal for mass vaccination campaigns.

Safety: Unlike mammalian cell-based vaccines, plant-derived vaccines pose no risk of contamination with human or animal pathogens, such as prions or oncogenic viruses. Plant viruses are not infectious to humans, further enhancing the safety profile of veggie vaccines. Additionally, oral vaccines reduce the risk of needle-stick injuries and eliminate the need for sterile administration environments.

Cold-Chain Independence: Many plant-based vaccines, particularly edible ones, are stable at ambient temperatures, reducing reliance on cold-chain logistics. For instance, lyophilized lettuce expressing hepatitis B antigens has shown long-term stability, making it suitable for distribution in regions with limited refrigeration infrastructure.

Successful Examples of Plant-Based Vaccines

Hepatitis B Virus (HBV): Hepatitis B remains a major global health threat, with 296 million people chronically infected in 2019. Transgenic plants such as potatoes, tomatoes, and lettuce have been engineered to express HBsAg, eliciting immune responses in animal models and human trials. A study by Pniewski *et al*. (2011) demonstrated that lyophilized lettuce expressing HBsAg induced mucosal immunity in mice, paving the way for oral vaccine development. These findings underscore the potential of plant-based vaccines to address chronic liver diseases caused by HBV.

SARS-CoV-2 (COVID-19): The COVID-19 pandemic highlighted the need for rapid vaccine development. Medicago’s plant-derived virus-like particle (VLP) vaccine, Covifenz, was one of the first plant-based vaccines to reach clinical trials, demonstrating immunogenicity and safety in adults. Additionally, transient expression of SARS-CoV-2 spike and nucleocapsid proteins in tobacco has shown promise as a candidate vaccine, with pre-clinical studies confirming robust antibody responses.

Influenza: Plant-based influenza vaccines have shown broad immune responses and protection in preclinical models. Hodgins *et al*. (2019) reported that a plant-derived VLP influenza vaccine protected aged mice from viral challenge, while Pillet *et al*. (2019) confirmed its immunogenicity in human trials. These studies highlight the versatility of plant-based platforms in addressing seasonal and pandemic influenza.

Human Immunodeficiency Virus (HIV): HIV remains a formidable challenge due to its genetic diversity. Plant-based systems have been used to produce HIV envelope proteins, such as gp140, in tobacco, eliciting neutralizing antibody responses in animal models. The use of plant viral VLPs to display HIV antigens further enhances immunogenicity, offering hope for a preventive vaccine.

Challenges and Limitations

Regulatory Hurdles: The regulatory framework for plant-based vaccines is still evolving. Concerns about genetically modified organisms (GMOs) and the potential for environmental contamination require stringent oversight. The World Health Organization (WHO) has held consultations to establish guidelines for plant-derived vaccines, but harmonized global standards are lacking. Regulatory approval processes must balance safety with the urgent need for accessible vaccines.

Dose Variability: Ensuring consistent antigen expression in plants is a technical challenge. Factors such as plant growth conditions, tissue type, and gene silencing can lead to variability in antigen levels, affecting vaccine efficacy. Advances in gene editing and expression optimization are being explored to mitigate this issue.

Immunogenicity: While plant-based vaccines have shown immunogenicity in preclinical studies, their ability to induce long-lasting immunity in humans remains under investigation. Mucosal adjuvants, such as cholera toxin B subunit (CTB), are being incorporated to enhance immune responses, as demonstrated in a tricomponent vaccine against cholera, rotavirus, and enterotoxigenic *E. coli*.

Public Perception: Public acceptance of GMOs is a significant barrier, particularly in regions with strong anti-GMO sentiments. Edible vaccines, in particular, face scrutiny due to concerns about unintended consumption or allergen transfer. Education and transparent communication are essential to build trust in this technology.

Future Prospects

Rapid Response to Pandemics: The speed of transient expression systems positions plant-based vaccines as a critical tool for pandemic preparedness. The success of Medicago's Covifenz demonstrates the potential to produce vaccines within weeks of identifying a pathogen's genetic sequence.

This capability is vital for combating emerging infectious diseases, such as novel coronaviruses or influenza strains.

Edible Vaccines for Low-Resource Settings: Edible vaccines hold immense promise for low-resource settings, where infrastructure for vaccine distribution is limited. Algae-based vaccines, which combine the benefits of plants with rapid growth and low-cost production, are an emerging frontier. For example, *Chlamydomonas reinhardtii* has been engineered to express antigens against cholera, offering a scalable oral vaccine platform.

Combination Vaccines: Plant-based systems enable the production of multicomponent vaccines that target multiple pathogens simultaneously. The fusion of antigens with mucosal adjuvants, such as CTB, has shown success in preclinical models, paving the way for vaccines that protect against multiple diseases.

Gene Editing and Synthetic Biology: Advances in CRISPR-Cas9 and synthetic biology are enhancing the precision and efficiency of plant-based vaccine production. These technologies allow for targeted gene insertion and optimization of antigen expression, addressing issues of dose variability and immunogenicity.

Conclusion

Veggie vaccines represent a transformative approach to disease prevention, harnessing the power of plants to produce safe, affordable, and scalable immunizations. From hepatitis B to COVID-19, plant-based vaccines have demonstrated their potential in preclinical and clinical studies, offering hope for addressing global health challenges. While regulatory, technical, and societal hurdles remain, advancements in gene editing, transient expression, and public engagement are paving the way for their widespread adoption. As we face the ongoing threat of pandemics and vaccine inequity, plant-based vaccines could become a cornerstone of global immunization strategies, ensuring that no one is left behind in the fight against infectious diseases.

Fermented Foods for a Healthy Gut: The Natural Way to Wellness

Poonam Bakhetia and Khushpreet Kaur

Introduction

"Good health begins in the gut" is a phrase strongly supported by modern nutrition science. Our digestive tract is home to trillions of microbes - bacteria, fungi and other organisms - collectively known as the gut microbiota. These tiny helpers play a crucial role in digestion, absorption, immunity and even mental health. An imbalance in this system, called dysbiosis, has been linked with obesity, diabetes, allergies, gastrointestinal problems and chronic diseases. One of the simplest, most natural and affordable ways to improve gut health is through fermented foods. For centuries, Indian households have prepared and consumed fermented foods such as curd, buttermilk, *dosa*, *idli*, *kanji*, pickles and fermented rice, often without realizing their scientific benefits. With the growing burden of lifestyle-related diseases, fermented foods are regaining importance in nutrition counselling.

Why Gut Health Matters

Nutrient Absorption: A healthy gut ensures proper breakdown and absorption of vitamins, minerals, and macronutrients.

Immunity: Around 70% of body's immune cells are located in the gut. Beneficial microbes act as the first line of defence against harmful pathogens.

Metabolic Health: Studies show that balanced gut bacteria regulate blood sugar, cholesterol and body weight.

Mental Health: Through the "gut-brain axis", microbes influence mood, memory and stress levels.

Nutritional Value of Fermented Foods

Fermentation is a process where micro-organisms like lactic acid bacteria (LAB), yeasts and fungi convert carbohydrates into simpler products (such as lactic acid). This not only improves flavor but also enhances nutrition:

Improved Digestibility: Fermentation breaks down lactose in milk, making curd easier to digest than milk.

Enhanced Vitamin Content: Fermented foods increase B-complex vitamins, vitamin K, and bioavailability of minerals such as iron and zinc.

Probiotic Effect: Certain strains of LAB act as probiotics, colonizing the gut with beneficial bacteria.

Reduced Anti-nutrients: Phytates and tannins in cereals/legumes are reduced, improving mineral absorption.

Recommended Daily Allowances (RDAs) and Fermented Foods

While RDAs do not specify a "fermented food intake," they do highlight the importance of nutrients like fibre, calcium and probiotics for gut and metabolic health.

Dietary Fibre: 25-40 g day^{-1} (ICMR-NIN, 2020).

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Table 1: Nutritional Benefits of Common Indian Fermented Foods

Fermented Food	Major Nutrients / Probiotics	Benefits
Curd / *Dahi*	Calcium, protein, lactic acid bacteria	Improves digestion, bone health, immunity
Buttermilk	Probiotics, electrolytes	Cooling, aids digestion, prevents dehydration
Idli / Dosa	Fermented rice & dal, B-vitamins	Easily digestible, enhances protein quality
Kanji (fermented carrot/beet)	Probiotics, antioxidants	Boosts gut flora, rich in carotenoids
Pickles (naturally fermented)	LAB, vitamin K, fiber	Gut health, enhances taste, appetite stimulant
Fermented Rice	LAB, B-vitamins	Cooling, probiotic-rich, satiety

Fermented foods like fermented whole grains, vegetables and pickles provide prebiotic fibres that nourish good microbes.

Calcium: 600-1000 mg day^{-1}. Curd, buttermilk and kefir (fermented milk) are excellent sources.

Probiotics: Though no exact RDA is given, clinical studies suggest that a bowl (200 ml) of curd or a glass of buttermilk easily provides the sufficient probiotics.

Scientific Evidence

- ✓ A 2021 study published in Nature Reviews Gastroenterology & Hepatology reported that regular consumption of fermented foods significantly increased gut microbial diversity and lowered key markers of inflammation, highlighting their role in improving overall gut health.
- ✓ Research by ICMR–NIN, Hyderabad (2020) emphasized that including fermented foods in daily diets enhances micronutrient absorption, strengthens gut immunity and is especially beneficial in addressing nutritional gaps in rural populations.
- ✓ The World Health Organization (WHO) and Food and Agriculture Organization (FAO) emphasize that fermented foods and probiotics can play an important role in disease prevention and health promotion worldwide.

Easy Ways to Add Fermented Foods in Daily Life

Our traditional Indian diets are full of wonderful fermented options. Here are some simple ways to include them in everyday life:

Breakfast Options

- ✓ *Idli, dosa or appam* made from fermented rice and lentil batter are light, tasty and easy to digest. Pair them with chutney or *sambar*.
- ✓ Fermented millet pancakes (*cheela*, *adai* or *dosa*) are healthy alternatives for those who want variety.
- ✓ *Dhokla* and *handvo* from Gujarat are also good choices for a quick and healthy start of the day.

Lunch and Dinner Additions

- ✓ Always try to include a bowl of curd, *raita* or buttermilk with your main meals. They cool the body and improve digestion.
- ✓ Fermented rice (*pakhala bhat* in Odisha, *pazhan kanji* in Kerala or *panta bhaat* in Bengal) can be enjoyed with vegetables or a light curry. These are excellent in summer to prevent heat strokes and provide strength.
- ✓ In South India, *mor kuzhambu* (buttermilk curry) is another traditional fermented dish.

Healthy Snacks and Drinks

- ✓ Kanji, a tangy drink made from fermented black carrots or beetroot, is popular in North India, especially during winters.

- ✓ Pickled vegetables such as mango, lemon, carrot or green chilli can be eaten in small amounts to spice up meals.
- ✓ Probiotic-rich smoothies can be made at home by blending curd with fruits like banana, mango or berries.
- ✓ In Rajasthan, people enjoy *raab,* a fermented millet-based drink, which is nourishing and cooling.
- ✓ You can also try *kombucha* (fermented tea) or water *kefir,* which are becoming popular, though our traditional drinks work just as well.

Keeping Traditional Practices Alive

It is important to preserve our food heritage, as our grandparents' diets were naturally rich in probiotics. Some regional examples include:

Odisha: *Pakhala bhat* (fermented rice with water and curd)

Kerala: *Pazhan kanji* (overnight fermented rice porridge)

Punjab: *Lassi* and *kanji* during summers and winters respectively

Gujarat: *Dhokla* and *khaman*

North India: Fermented *idli/dosa* batter, *kanji* and pickles

Rajasthan: *Raab* made with *bajra*

These foods not only improve digestion but also help the body use vitamins and minerals more efficiently.

Other Simple Everyday Ideas

- ✓ Add a spoonful of homemade pickle or fermented *chutney* with your meals.
- ✓ Use miso paste or soy sauce (both fermented foods) in small amounts while cooking Asian-style dishes.
- ✓ Try fermented dairy products like *paneer* stored in whey or *kefir* (if available).
- ✓ Use fermented flour batters to make *rotis, thepla* or *parathas* for a nutritious twist on daily meals.

Adding fermented foods does not require special effort. Just by including curd, buttermilk, pickles or traditional recipes, we can naturally take care of our gut. These foods are time-tested, economical and deeply rooted in our culture - a natural path to wellness that our ancestors wisely followed.

Table 2: Tips for Safe Consumption of Fermented Foods

Do's	Don'ts
Use clean utensils and water	Avoid excessive oil/salt/ pickles
Consume fresh homemade curd	Don't store fermented foods too long in heat
Prefer natural fermentation	Avoid artificially flavored probiotic drinks
Combine with fibre-rich foods	Don't rely only on supplements

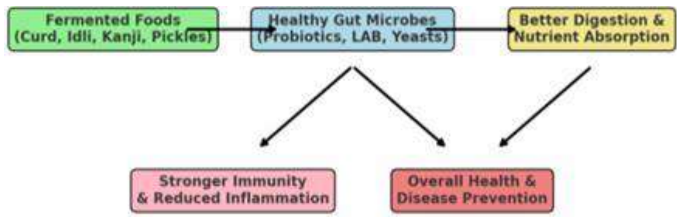

Fig. 1: Gut-Food-Health Connection

Conclusion

Fermented foods are nature's own probiotics, combining tradition, taste and therapeutic value. They not only improve gut health but also support overall nutrition - enhancing digestion, boosting immunity and ensuring better absorption of key vitamins and minerals. In a country like India, where fermented foods are part of culture, making them a regular part of daily diet is both affordable and sustainable.

Thumb Rule: “Feed your gut right and it will take care of your health.”

National Pest Surveillance and Response System: A Pillar for Sustainable Plant Protection in India

Akash Kumar and Sanjeev Ravi

Abstract

Pest surveillance means keeping a regular watch on insects, diseases, and weeds that damage crops. In India, different organizations like ICAR, SAUs, KVKs, and State Departments work together to observe pest activity and warn farmers in time. The main aim of the National System for Pest Surveillance and Response Mechanism is to create one strong and uniform system across the country. Modern tools like Artificial Intelligence (AI), Machine Learning (ML), and remote sensing will help in quick and accurate pest forecasting. Regular surveys such as fixed plot, roving, and random surveys will be carried out to collect field data. The system also focuses on early detection of new or invasive pests to stop their spread. Mapping pest hotspots will help in planning better pest control methods. Farmers will receive timely advisories for managing pest outbreaks effectively. This coordinated system will save crops, reduce pesticide use, and protect India's agricultural productivity.

Introduction

Pest surveillance involves continuous monitoring of pest populations, their incidence, and the resulting crop damage to provide early warnings for effective crop protection. In India, it plays a crucial role in forecasting outbreaks of insect pests, diseases, and weeds, while also assessing the role of bio-control agents in pest regulation. The system operates under the coordination of organizations such as DPPQS, ICAR, State Agriculture and Horticulture Departments, KVKs, SAUs, and AICRP Centers, which work collectively to issue timely advisories and monitor pest outbreaks and invasive species.

At present, field surveys are conducted manually, making the process time-consuming and less efficient. Therefore, there is a growing need for technology-based contingency plans that define the responsibilities of different stakeholders and enable rapid detection, response, and eradication of pests. Developing such plans ensures preparedness, coordinated action, and the use of knowledge from previous successful eradication programs to protect agriculture and related ecosystems effectively. Major objectives of pest surveillance are:

- ✓ To develop a unified, technology-driven national pest surveillance system integrating Artificial Intelligence (AI), Machine Learning (ML), and

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digital tools for real-time pest monitoring and forecasting.

- ✓ To strengthen collaboration among research institutes, government agencies and farmers for data sharing, rapid response, and adaptive pest management strategies.
- ✓ To establish proactive measures for early detection and eradication of invasive pests to safeguard agricultural productivity, biodiversity, and national biosecurity in the future.

Important terms used in Pest Surveillance and Pest Monitoring

Pest survey: Pest survey is a detailed collection of pest population information at a particular time in a given area or an official procedure conducted over a defined period of time to determine the characteristics of a pest population or to determine which pest species occur in an area.

Pest Surveillance: The regular surveys of same place or locality at consistent intervals to assess the changes in population dynamics of pest species, natural enemies over a time.

Pest Monitoring: Pest monitoring involves determining number and life stages of pest present in the location only. It is considered the first step helping you to know what is causing damage and when to act. Invasive Pests-Invasive species, alien species, exotic pests, or invasive alien species, are common names that categorize non-native animals, insects, microbes, diseases, or plants (weeds) that are pests. Invasive Alien Species are non-native or exotic organisms that occur outside their natural adapted habitat and dispersal potential & they become established in natural or semi natural ecosystems or habitat and threaten native biological diversity.

Types of Pest Surveys

To monitor pest populations effectively, several types of surveys are conducted depending on the purpose and scale of observation:

Qualitative Survey: This survey helps in the detection and identification of pests in a specific area. It provides basic information on the presence or absence of a pest species.

Quantitative Survey: This type of survey measures the population density of pests in numbers, across time and locations, to understand their population trends and forecast possible outbreaks.

Fixed Plot Survey: In this method, a one-acre field is divided into five small plots four near each corner and one in the center. Regular pest observations are made in these marked plots, which are kept pesticide-free until the pest population reaches the Economic Threshold Level (ETL). This allows accurate tracking of pest buildup.

Rapid Roving Survey: A mobile and quick assessment survey conducted every 7-10 days across randomly selected fields following a planned route. Observations are recorded diagonally across the field, covering 200-250 km or 20-25 spots a day. Data are collected at about every 10 km on both sides of the road, and surveyors enter at least 100 meters into the field. If a pest outbreak is detected, immediate warnings are issued to farmers the same day.

Random Survey for Invasive Pests: This survey is conducted near import points, ports, and quarantine stations to detect the entry or presence of new and invasive pest species at an early stage.

Advantages of Pest Surveillance

- ✓ Provides data on pest population behavior and crop damage at different growth stages.
- ✓ Helps track the natural enemies of pests and their effectiveness in control.
- ✓ Studies the influence of weather and environmental conditions on pest and natural enemy populations.
- ✓ Identifies changes in pest intensity or status on specific crops.
- ✓ Aids in developing Integrated Pest Management (IPM) strategies for sustainable agriculture.
- ✓ Assesses the impact of new cropping patterns or varieties on pest behavior.
- ✓ Helps alert farmers and officials about possible pest outbreaks.
- ✓ Supports evaluation of farming practices that influence pest incidence and management efficiency.

Outcomes of Pest Surveillance

- ✓ Early detection of pest occurrences, outbreaks, and sudden increases in pest populations.
- ✓ Enables quick action with appropriate pest control methods before serious crop loss occurs.
- ✓ Helps identify pest-endemic areas, hotspots, and pest-free zones.
- ✓ Facilitates timely advisories to farmers and agricultural authorities.
- ✓ Supports effective management of pest emergencies and prevents their spread to new areas.
- ✓ Encourages proactive pest management planning and ensures the availability of required control materials.
- ✓ Promotes phytosanitary measures and supports safe, pest-free international trade in agricultural products.

Mapping of Pest and Disease Hotspots

A pest hotspot is an area where a particular pest appears regularly each season on a specific crop. Mapping such hotspots helps researchers and farmers plan pest control strategies more effectively. Currently, rapid roving surveys give information on pest conditions only for that season. However, systematic hotspot mapping, including for locusts in desert regions, helps predict pest trends, improve preparedness, and reduce unnecessary pesticide use.

Existing Pest Surveillance System in India

India has a well-coordinated pest surveillance network managed by the Directorate of Plant Protection, Quarantine & Storage (DPPQS) through its Central Integrated Pest Management Centers (CIPMCs), along with State Agriculture and Horticulture Departments, SAUs, KVKs, ICAR Institutes, and AICRP Centers.

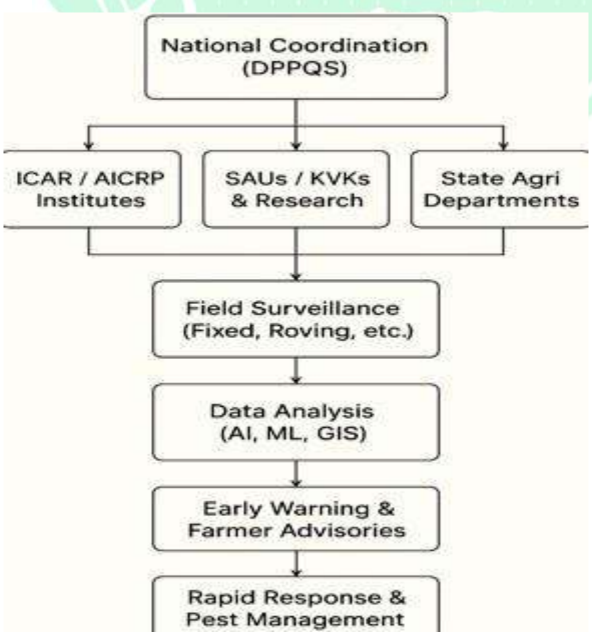
Planning and Route Identification: Before each cropping season (*Kharif* or *Rabi*), survey routes are selected based on pest history and major crops. In Rajasthan and Gujarat, Locust Control Offices (LCIPMCs) carry out similar surveys for desert locusts.

Survey Teams: Specialized teams are formed with trained experts from DPPQS, ICAR, SAUs, and State Departments. Joint surveys are conducted when pest threats are severe or widespread.

Frequency and Coverage: Surveys are conducted regularly at seven-day intervals, covering large crop areas (about 200-250 km day^{-1}). Priority is given to pest-prone regions and major cropping zones.

Observations: Pest observations are taken every 10 km along both sides of the route after entering about 100 meters into the field. The intensity of pest attacks is categorized as trace (negligible), low (below ETL), moderate (near ETL), or high (above ETL).

Rapid Roving Surveys: These are conducted during the crop season to quickly assess pest conditions in randomly chosen fields. Data from these surveys help issue timely alerts and guide pest management activities.



Forewarning and Advisory: Based on survey findings, immediate forewarnings and advisories are issued to farmers and state authorities for taking appropriate control measures. The information is shared through reports, digital platforms, and local agricultural offices for quick action.

Conclusion

Pests continue to be one of the major threats to agricultural productivity and food security. In the modern era, where climate change and global trade have increased the movement of pests across regions, a National Pest Surveillance and Response Mechanism is no longer optional it is essential. By integrating advanced technologies with institutional coordination, India can shift from a reactive to a proactive pest management approach. This will not only protect farmers' livelihoods but also safeguard the nation's agricultural future. A robust, technology-based surveillance and response network will empower the country to detect, prevent, and manage pest outbreaks efficiently ensuring sustainable crop production and a secure food system for generations to come.

Reference

Government of India, Ministry of Agriculture & Farmers Welfare, Department of Agriculture & Farmers Welfare, Directorate of Plant Protection, Quarantine & Storage. (2023). Standard Operating Procedure (SOP) on National System for Pest Surveillance and Response Mechanism. Faridabad, India. Retrieved from: https://www.ppqs.gov.in/en/publication

Crop Model: Tool for Climate Smart Viticulture

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Abstract

The global climate is changing and horticulture will have to adapt to ensure sustainability and survival. Due to the complexity of both agricultural systems and climate change, crop models are often used to understand the impact of climate change on agriculture and to assist in the development of adaptation strategies. Crop models integrate the understanding of crop physiology gathered from many years of laboratory and field experimentations and therefore provide an effective means for investigating crop responses to climate change and alternative management scenarios. Using these different data, the models can simulate the dynamics of crop development (or phenology), biomass accumulation, yield, water and nutrient uptake. Crop models are part of larger dynamic agricultural model systems that include economics and human behavior.

Introduction

Crop weather modelling plays a pivotal role in advancing climate-smart viticulture by integrating meteorological, physiological and phenological data to optimize vineyard management under changing climatic conditions. These models simulate grape-vine responses to variable weather parameters such as temperature, precipitation, solar radiation and humidity, thereby supporting adaptive decision-making for sustainable wine production. Model like DSSAT, APSIM, and STICS, VINELOGIC, VIMO, Crpsyst, NVINE, Vitisim and SWAP combined with remote sensing and GIS technologies enables precise assessment of vine growth, yield potential and stress risk. By coupling climate projections with vineyard-specific data, crop weather models facilitate the development of resilient viticultural strategies that mitigate climate-related risks, improve water and nutrient use efficiency and ensure consistent grape quality in the face of increasing climatic variability.

Types of model

Based on the purpose for which they are designed, crop models have been classified into different types:

Crop growth stimulation model: Defined as a mathematical representation of the complex physical, chemical, and physiological mechanisms underlying plant growth responses. The impact of meteorological variables (radiation, temperature, wind, humidity, etc.) on specific processes such as photosynthesis, transpiration or respiration can be adequately simulated by means of a set of mathematical equations based on experiments or available knowledge of the particular process.

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Crop weather analysis model: Crop-weather analysis models providing a running account of the accumulated daily crop responses to selected agrometeorological variables as a function of crop development time. It uses soil moisture or evapo-transpiration and other data derived or observed on a day-to-day basis together with other data relating to morphological development, vegetative growth or crop yield. Standard climatic data are used as the primary input. Some processes or crop response functions such as soil moisture distribution or fertilizer response are pre-programed; however, statistical techniques (e.g., multiple regressions) are used to evaluate the weighting coefficients in the final equation.

Empirical/statistical models: It uses a sample of yield data from an area (e.g., experimental field, crop district, or region) and a sample of weather (and soil) data from the same area to produce coefficient estimates by some sort of regression technique. The validity and potential application of these models depends on the representativeness of the input data, the selection of variables and the design of the model.

Other models

Deterministic models: Deterministic models make definite predictions for quantities (e.g. crop yield or rainfall) without any associated probability distribution, variance or random element. However, differences due to inaccuracies in recorded data and heterogeneity in the material concerned are inherent in biological and agricultural systems. In some cases, deterministic models may be sufficient in spite of these inherent differences, but in other cases they may not be sufficient, for example in the case of rainfall prediction. The greater the uncertainties in the system, the more insufficient are the deterministic models.

Stochastic models: Stochastic model that gives an expected mean value as well as the associated variance should be developed when variation and uncertainty reach a high level. However, stochastic models tend to be technically difficult to handle and can quickly become complex. Therefore, it is advisable to initially try to solve the problem with a deterministic approach and to try the stochastic approach only if the deterministic and stochastic results are not satisfactory. The output is evaluated at a fixed rate and each output has a probability. Because these models are complex, they can only be used if the deterministic model fails.

Dynamic models and Static models: In a static model, time is not a variable even if the end-products of cropping systems accumulate over time. On the other hand, most dynamic models explicitly incorporate time as a variable and are first expressed as differential equations.

Mechanistic models: A mechanistic model is one that uses lower-level characteristics to explain how the system behaves. Therefore, at the lowest levels (e.g., Cell division) there is some mechanism, understanding or explanation. These models are capable of mimicking relevant physical, chemical or biological processes and describe how and why a particular response occurs.

On the basis of this information, further parameters and variables have been added to explain crop yields. The modeler usually starts with some empirism. Therefore, the system can be divided into components and assigned processes. They show the system behavior. These models describe the relation between weather and yield.

Explanatory models: Consist of quantitative descriptions of the mechanisms and processes involved that are responsible for the behavior of the system. For an explanatory model the system is analyzed and its process and mechanism was quantified separately. The model is then build by integrating these description for the entire system. They describe the mechanisms and methods of system behavior. These models are developed by independently quantifying the processes and mechanisms of a system.

Steps in modelling

The processes necessary to develop a model are outlined below.

- ✓ Define goals: Agricultural system, Horticulture system.
- ✓ Define the system and its boundaries: Choose the variables. State variables include measurable factors such as soil moisture content and crop yield. Rate variables indicate the rate at which certain system processes take place, e.g. photosynthesis and transpiration. Factors such as sunlight and rainfall that drive the system are external to it but have an effect on it. Auxiliary variables are intermediary molecules produced during plant life cycle, e.g., dry matter partitioning and water stress.
- ✓ Quantify relationships (evaluation)
- ✓ Calibration: It is necessary to calibrate the model before use. Calibration evaluates and fine-tunes a data collection model using a specified set of inputs.
- ✓ Validation: The accuracy of the model is tested using local field data different from calibration data.
- ✓ Sensitivity analysis: To determine its response, the model is examined with various alterations to the input elements.

Crop model applications

Simulation models are increasingly used in research, teaching, agricultural and resource management, policy analysis and production forecasts. They can be applied in crop system management, research and policy analysis.

Site-specific experimentation: Specific site selection can be performed using the model. Crop models can be used for estimating the performance of crops in regions where the crop has not been grown before or under the optimal conditions.

Yield analysis: A sound physiological background model can be adopted to extrapolate to other environments. Simulation models have been used to determine climatically-determined yields for various crops. Through the modeling approach, yield reductions caused by non-climatic causes (e.g. delayed sowing, crop spacing, soil fertility, pests, and diseases) can be quantified.

Climate change projections: The variability of our climate and in particular the associated extreme weather conditions are currently a matter of concern for the scientific community and the general public. Crop models have been widely used across continents to study the potential impact of climate change. Increased concentrations of CO_2 and other greenhouse gases are expected to increase the Earth's temperature. Crop production is highly dependent on weather, so any change in the global climate will have a significant impact on crop yields and productivity. Temperature rises and carbon dioxide affects biological processes such as respiration, photosynthesis, plant growth, reproduction and water use. A better understanding of the effects of climate change will therefore help scientists to guide farmers in decision-making on crop management, such as the selection of crops, cultivars, sowing dates and irrigation schedules to minimize risks.

Research understanding: Model development ensures the integration of research knowledge acquired through discrete disciplinary research, facilitates the identification of the main factors that drive the system and highlights areas where knowledge is lacking. Therefore, adopting a modeling approach could contribute to more targeted and effective research planning.

Integration of knowledge across disciplines: The adoption of a modular framework will allow the integration of basic research carried out in different regions, countries and continents. It ensures a reduction of research costs (e.g. reduction of duplication of research) as well as collaboration between researchers at international level.

Improvement in experiment documentation and data organization: The development, testing and application of simulation models requires the use of a large quantity of technical and observational data supplied in a given unit in a specific order. To handle data, the modeler must resort to formal data organization and database systems.

Breeding and introduction of a new crop variety: Variety development and release is a complex process that may extend over a period of 5-15 years. These studies can help reduce the number of sites/seasons required for field evaluation and thus increase the efficiency of the variety development process. By modeling a range of probable genotypes and selected environments that are known to discriminate between genotypes, it is possible to identify the crop parameter that determines the specific interaction. Hypothetical values can then be modeled by combining the crop parameters that confer the greatest advantage as an indication of suitable traits and breeding objectives.

Crop model in viticulture

Achieving desirable vineyard outcomes depends on the decisions made by grape growers at both long-term strategic planning timescales and short-term operational timescales, together with a large number of exogenous factors, including climate and weather. Crop models are a promising approach for bringing diverse data streams together into robust decision-making processes for viticulture.

Crop models have been used to predict outcomes such as phenology, canopy management, vegetative growth, photosynthesis rate, end-of-season yield (Nogueira *et al*., 2018) and berry compositional attributes such as sugar concentration (Andreoli *et al*., 2019) as well as how these outcomes are impacted by exogenous factors (Miras-Avalos *et al*., 2018) Andreoli *et al*., (2019) recently observed phenological phases (bud break, flowering, fruit-set, beginning of ripening, veraison and harvest) and physiological parameters such as *LAI*, berry weight and berry sugar content by using IVINE model. The model results were accurate in representing both the time trend and the numerical values of pheno-physiological variables related to the specific type of vine cultivar.

Dynamic crop modelling in viticulture can be focused on the simulation of a particular process or on the whole plant growth (Moriondo *et al*., 2015). Lebon *et al*. (2003) used a dynamic model to simulate the seasonal dynamics of soil-water balance in vineyards and demonstrated that this process can be adequately replicated by this model. Nendel and Kersebaum (2004) skilfully simulated nitrogen dynamics in vineyard soils using the NVINE model. Ben-Asher *et al*. (2006) assessed the skill of the soil, water, atmosphere, and plant (SWAP) model to estimate salinity effects in grapevine production. Their findings show that when water quality is the only variable considered, the model can produce realistic responses to salinity. Poni *et al*. (2006) used STELLA software to build a model to predict the daily carbon balance and dry matter accumulation on grapevine vertical shoots to help choose appropriate training and pruning strategies. Celette *et al*. (2010) used the Walis model to simulate water partitioning on an intercropped vineyard. Webb *et al.* (2007) used the VineLOGIC model (Godwin *et al.*, 2002) to determine grapevine phenology. Cola *et al*. (2014) developed a new dynamic model MoDeM_IVM DSS (Monitoring and Decision Making in Integrated Vineyard Management Decision Supporting Syste-ms) for predicting grapevine seasonal dynamics, source-sink balance, and yield, showing high potential for its inclusion in viticultural decision supporting systems and technical assistance.

Limitation of crop model

- ✓ An ideal crop model cannot be developed because of complex biological system.
- ✓ Plant, soil and meteorological data are rarely precise and come from nearby sites.
- ✓ Sampling errors also contribute to inaccuracies in the observed data.
- ✓ Model performance is limited to the quality of input data.
- ✓ Inherent soil heterogeneity over relatively small distances.
- ✓ Inappropriate results for Heterogeneous plot.

Conclusion

Crop weather modelling represents a vital scientific approach for enhancing climate-smart viticulture by linking climatic variability with grape-vine growth dynamics and productivity. Through the integration of predictive modelling, remote sensing and decision-support systems these tools enable viticulturists to anticipate and mitigate adverse weather impacts, optimize resource manage-ment and improve grape quality. The continued refinement of such models, incorporating high-resolution climate data and advanced machine learning algorithms will further strengthen vineyard resilience to climate change. Ultimately crop weather modelling supports sustainable viticultural practices, ensuring environmental stewardship, economic stability and consistent wine quality in a rapidly evolving global climate.

References

Andreoli, V., Cassandro, C., La Iacona, T. and Spanna, F., (2019). Description and pre-liminary simulations with the Italian vineyard integrated numerical model for estimating physiological values (IVINE). *Agronomy*, 9 (2): 94.

Ben-Asher, J., van Dam, J., Feddes, R. A. and Jhorar, R. K. (2006). Irrigation of grapevines with saline water: II. Mathematical simulation of vine growth and yield. *Agriculture Water Management*, 83(1-2): 22-29.

Nendel, C. and Kersebaum, K. C. (2004). A simple model approach to simulate nitrogen dynamics in vineyard soils. *Ecological Model*, 177(1-2): 1-15.

Nogueira Júnior, A. F., Amorim, L., Savary, S. and Willocquet, L. (2018). Modelling the dynamics of grapevine growth over years. *Ecological Model*, 369: 77-87.

Celette, F., Ripoche, A. and Gary, C. (2010). WaLIS-A simple model to simulate water partition-ing in a crop association: the example of an intercropped vineyard. *Agriculture Water Management*, 97: 1749-1759.

Cola, G., Mariani, L., Salinari, F., Civardi, S., Bernizzoni, F., Gatti, M. and Poni, S. (2014). Description and testing of a weather-based model for predicting phenology, canopy development and source-sink balance in *Vitis vinifera* L. cv. Barbera. *Agricultural and Forest Meteorology*, 184: 117-136.

Godwin, D., White, R., Sommer, K. J., Walker, R., Goodwin, I. and Clingeleffer, P. (2002). Vine LOGIC-a model of grapevine growth development and water use. Dundon C, Hamilton R, Johnstone R, Partridge S (Eds.), Managing Water. *Australian Society of Viticulture and Oenology*, 46-50.

Lebon, E., Dumas, V., Pieri, P. and Schultz, H. R. (2003). Modelling the seasonal dynamics of the soil water balance of vineyards. *Functional Plant Biology*, 30(6): 699-710.

Miras-Avalos, J. M., Uriarte, D., Lakso, A. N. and Intrigliolo, D. S. (2018). Modeling grapevine performance with 'VitiSim', a weather-based carbon balance model: Water status and climate change scenarios. *Scientia Horticu-lturae*, 240: 561-571.

Moriondo, M., Ferrise, R., Trombi, G., Brilli, L., Dibari, C. and Bindi, M. (2015). Modelling olive trees and grapevines in a changing climate. *Environmental Modelling and Software*, doi:10.1016/j.envsoft.2014.12.016.

Poni, S., Palliotti, A. and Bernizzoni, F. (2006). Calibration and evaluation of a STELLA software-based daily CO_2 balance model in *Vitis vinifera* L. *Journal of the American Society for Horticultural Science*, 131(2): 273-283.

Webb, L. B., Whetton, P. H. and Barlow E. W. R. (2007). Modelled impact of future climate change on the phenology of winegrapes in Australia. *Australian Journal of Grape and Wine Research,* 13(3): 165-175.

From Soil to Soul: Healing the Earth, One Farm at a Time

Srishti

Introduction

What if farming could be the solution to some of our biggest environmental problems, rather than a contributor? This is the central promise of regenerative agriculture, an approach that focuses on rebuilding soil organic matter to capture carbon. Regenerative agriculture focuses on improving and restoring the health of soil through practices like minimizing soil disturbance, using cover crops, diversifying crops, and integrating livestock to enhance soil structure, nutrient cycling, and microbial activity. By fostering healthy soils, this farming method helps sequester carbon from the atmosphere, improves water conservation, builds resilience against drought, and can increase crop yields and quality over time, creating a more sustainable and profitable food system.

Principles of Regenerative Agriculture

There are some Core Principles & Practices like

Minimal Soil Disturbance: Practices like no-till or reduced-till farming, where seeds are drilled directly into the soil rather than plowing, help preserve soil structure and prevent carbon loss.

Cover Crops: Growing plants specifically to cover the soil after the main crop is harvested helps keep soil covered and alive, protecting it from erosion and adding organic matter.

Crop Diversification: Rotating different crops or planting diverse species in a single system improves soil health by providing a wider range of nutrients and supporting a more robust microbial community.

Integration of Livestock: Rotational grazing can help manage soil fertility, add organic matter, and increase the overall health of the ecosystem. .

Composting and Organic Fertilizers: Using organic materials and compost enhances soil fertility and microbial life, providing essential nutrients for plants.

Enhanced Soil Health: Regenerative agriculture increases soil organic matter, which improves soil structure, water-holding capacity, and nutrient availability.

Climate Change Mitigation: Soils act as a natural "carbon sink," and these practices help store more atmospheric carbon in the soil, reducing greenhouse gas emissions.

Improved Water Management: Healthy, well-structured soils absorb and retain more water, leading to better drought resistance and reduced runoff.

Increased Productivity: Over time, healthy soils lead to more robust root development, better nutrient absorption, and increased crop yields and quality.

Ecological Restoration: By building biodiversity and restoring degraded lands, regenerative agriculture creates more resilient and sustainable farming systems.

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Economic Barriers: The transition to regenerative practices can involve short-term yield declines or financial burdens for farmers.

Knowledge Gaps: A lack of extensive, long-term empirical evidence on the benefits and economic viability of certain practices can hinder adoption.

Policy Constraints: Clear policies, incentives, and certification systems are needed to support and accelerate the widespread adoption of regenerative agriculture.

Benefits of Regenerative Agriculture

Enhanced Crop Resilience and Nutrition: Regenerative practices like no-till farming, cover cropping, and diverse rotations can significantly boost the nutritional value of crops. For instance, farms employing these methods have reported up to 60% higher levels of antioxidants and essential minerals in their produce compared to conventional farms. These nutrient-dense foods not only improve human health outcomes but also command premium market prices.

Increased Farm Productivity: Healthy soils and enhanced nutrient cycling lead to increased crop yields and improved farm productivity. Improved soil structure, increased water infiltration, and enhanced nutrient availability create optimal conditions for plant growth, leading to higher yields and increased farm productivity. This increased productivity contributes to food security and enhances the economic viability of farming operations.

Climate Change Mitigation: By sequestering carbon in the soil, regenerative agriculture contributes to climate change mitigation, helping to reduce the impacts of global warming. Increased soil carbon storage not only removes carbon dioxide from the atmosphere but also improves soil health, enhances water retention, and increases farm resilience to climate change impacts. This makes regenerative agriculture a crucial strategy for addressing the climate crisis and building more sustainable agricultural systems.

Advancements in Soil Carbon Monitoring: Innovations like AI-driven Soil Organic Carbon (SOC) Copilots are enabling large-scale, localized analysis for sustainable agriculture. These tools automate the ingestion of complex data to provide insights into soil health and regenerative practices. For example, integrating public data and specialized models has shown that composting can mitigate SOC loss, even in areas affected by extreme weather conditions.

Corporate Investment in Regenerative Practices: Major corporations are increasingly investing in regenerative agriculture. For instance, McDonald's announced plans to invest $200 million over the next seven years to promote regenerative agriculture practices on U.S. cattle ranches. This initiative aims to enhance soil health, conserve water, and reduce the use of 0000 are driving the adoption of regenerative practices on a larger scale.

Conclusion: With the clear benefits and increasing momentum behind regenerative agriculture, the question remains: how will we, as a global community, choose to support and expand these vital practices.

Nutritional Composition and Value Addition of *Moringa oleifera*

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Introduction

Moringa (*Moringa oleifera* Lam.), a member of the Moringaceae family, is native to the Indian subcontinent and has spread to tropical and subtropical regions across the globe. Benzolive, Drumstick, Horseradish, Kelor, Marango, Mlonge, Mulangay, Saijihan, Sajna, and Miracle trees are some of the names for the tree. Despite having low-quality lumber, this perennial softwood tree has been recommended for generations for traditional industrial and medicinal applications. *Moringa oleifera* is a staple food that is often regarded as the "natural nutrition of the tropics." Many nations, particularly those in India, Pakistan, the Philippines, Hawaii, and many African countries, eat the leaves, fruits, flowers, and pods of this tree as a highly nutritious vegetable. As a good source of natural antioxidants, moringa leaves have been described as a rich source of β-carotene, protein, ascorbic acid, calcium, and potassium. They also contain a variety of antioxidant compounds, including flavonoids, phenolics, carotinoids, and ascorbic acid, which extend the shelf life of foods that contain fat. Furthermore, a collection of unique molecules including sugar and rhamnose abnormal sugar-modified glucosinolates was discovered in Moringa. Because Moringa has therapeutic and medical qualities, it is imperative that it be preserved. These days, consumers often search for food items that are ready to eat. As a result, maintaining the drumstick becomes essential. Fresh vegetables can be canned, fermented, dried, frozen, or pasteurized. Drumsticks can be used in a variety of recipes as a thickening and flavoring ingredient. It has a distinct palatable flavor and contains a lot of glutamic acid. Convenience meals fall into one of three categories: ready to use, ready to cook, or ready to consume. Moringa pulp can be added to a variety of goods to improve their functional and sensory qualities. Traditionally, moringa pods are used to soups, curries, sambhar, and other dishes to enhance their viscosity and sensory qualities. To increase viscosity, thickening agents such as xanthan gum in chutneys and starch in soups are added to food products like dal, soup, and chutney. Moringa pulp can be added to food products to improve their nutritional value and sensory appeal while lowering the need of thickeners.

Various value added products of Moringa

Oil: Ben oil, also known as moringa oil, is given to seeds. The kernel, or dehulled seed, has a pale yellow oil content of about 42%. Its minute propensity to deteriorate and turn rotten and sticky makes it a useful moisturizer for delicate equipment like watches. Additionally, it works well as vegetable cooking oil. The range of the free fatty acid concent-

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ration is 0.5% to 3%. According to Indian Ayurveda, moringa oil is used to treat a variety of illnesses in the regional medical system, especially in South Asia. It is said to have antitumor, antipyretic, antiepileptic, anti-inflammatory, antiulcer, antispasmodic, diuretic, antihypertensive, cholesterol-lowering, antioxidant, antibacterial, and antifungal properties. Because moringa oil has soaking qualities, it is used in skincare treatments.

Leaf Tablets: Tablets made from moringa leaves offer a suitable way to take advantage of this superfood's many health advantages. They offer essential nutrients in a convenient manner, making them a useful supplement to a diet that prioritizes health.

Tea: Dried leaves can be use for preparation of herbal tea.

Leaf Powder: Moringa leaves can be dried and comminute for use in smoothy soups and as a nutritional additive.

Juice: In a mortar, fresh leaves are crushed and ground with a small amount of water. For bigger production, immature moringa shoots (less than 40 days old) are pounded in a hammer mill with a small amount of water (about one liter for every 10 kg of fresh material). After that, it is made clearer, diluted with water, and sweetened to taste. If not, a liter of water can be mixed with a teaspoon of additional moringa leaf powder. After that, it is combined, filtered, and sugar is added. A refrigerator is used to store juice or juice concentrate.

Dry Flowers salad: The blooms should be cooked and eaten since they are a wonderful source of potassium and calcium. They taste like mushrooms when fried either by themselves or in a batter. Moringa blooms can be steamed and consumed as a salad or combined with any leaf meal.

Curries: The entire young, pliable pod is either cooked and consumed or used to make curries. The pulp and immature seeds are still palatable right before ripening starts in older pods that have a pronounced external expansion. Pods are cut into 5cm lengths and cooked with lentils in water to make a meal. The meat within the pod segments is consumed. If not, pods can be opened, the meat and young, immature seeds removed, and then the pods are boiled for a short while in water. In edible pods, the seeds should be white. In order to preserve the winged shells and as much of the soft white flesh as possible, the seeds should be grazed out.The sticky, bitter film is removed by rinsing it with water. To make it taste like sweet groundnuts, it is roasted, cooked in oil, or combined with rice. The meat can be added to other sauces, used to make soup, or sliced into strips and steamed or fried. Moringa pods that are very young less than 1 cm thick and easily break are chosen and trimmed into 3-cm lengths. It should be marinated in a mixture of oil, vinegar, salt, pepper, garlic, and parsley after ten minutes of steaming.

Beans: Very immature moringa pods (should be less than 1 cm thick and snap readily) are used to make a recipe known as moringa beans. After being cut into any length of pieces, the pods are boiled or steam-cooked until they are soft.

Conclusion

High levels of vitamins and minerals as well as strong antioxidants are just a few of the many nutritional advantages that moringa leaves provide. Their utility and marketability are improved by the many value-adding techniques, including drying and powdering, producing tea, extracting oil, making capsules, and fortifying foods. Moringa leaves can be efficiently used in a variety of industries by utilizing these value-adding strategies, improving health and providing producers with financial prospects.

Aeroponics: Revolutionizing Agriculture through Suspended Growth Technology

Anoop Kumar Bishoni and Shubham Jamwal

Introduction

Imagine walking into a vertical farm where plants dangle in mid-air without soil, their roots suspended and regularly bathed in a nutrient-rich mist. This is aeroponics a revolutionary approach to growing food that challenges traditional agriculture. Derived from the Greek words 'aero' (air) and 'ponos' (labor), aeroponics means working with air to cultivate plants. While the concept emerged in the 1920s, aeroponics remained largely experimental until the late 1990s when NASA recognized its potential for growing food in space. Today, this innovative technology uses up to 95% less water than traditional farming, grows crops three times faster, and dramatically reduces pesticide dependence. As our world faces urbanization, climate change, and dwindling resources, aeroponics offers a practical solution for sustainable food production.

How Aeroponics Works?

At its core, aeroponics delivers nutrients directly to plant roots through fine mist rather than through soil. Plants are positioned in support structures with roots suspended in a dark, enclosed chamber. Every few minutes, a precisely timed misting system sprays nutrient-rich aerosol directly onto the roots droplets so fine (20-100 microns) that they provide maximum surface area for nutrient absorption while maintaining proper humidity. The system operates on a closed-loop design. Nutrient solution is captured, filtered, and recycled multiple times before requiring replacement. This recycling mechanism is what enables aeroponics to use so dramatically less water than any other cultivation method.

Key System Components

Reservoir Tank: Holds nutrient solution.

High-Pressure Pump: Delivers pressurized nutrient mist.

Misting Nozzles: Break down solution into fine droplets.

Root Chamber: Light-proof growing space

Timer System: Controls misting frequency and duration.

Nutrient Solution: Contains all macro and micronutrients.

Monitoring System: Sensors track pH, nutrient levels, temperature, and humidity with automated adjustments.

Key Advantages

Water Efficiency: Traditional soil farming requires 200-400 liters of water per kilogram of tomatoes. Aeroponics uses only 20 liters a 95% reduction. This extraordinary efficiency through closed-loop recycling makes aeroponics invaluable in water-scarce

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regions worldwide.

Accelerated Growth and Higher Yields: Optimal oxygen exposure and precise nutrient delivery create ideal growing conditions. Lettuce that normally requires 35-45 days reaches maturity in 20-25 days. Research shows yield improvements: tomatoes (+33%), cucumbers (+39%), and peppers (+43%). Vertical stacking can produce up to 390 times more food per square foot compared to traditional field farming.

Reduced Chemical Inputs and Disease Prevention : Sterile, soil-free environments eliminate soil-borne diseases, pathogens, and pests, dramatically reducing pesticide and fungicide requirements. Produce is cleaner with no risk of E. coli or Salmonella contamination. Nutritional quality is often superior, with higher concentrations of vitamins, minerals, and beneficial phytonutrients compared to conventionally grown produce.

Year-Round Production: Climate-controlled environments enable consistent production regardless of external weather or season. This independence from weather patterns makes aeroponics particularly valuable for urban food security and in regions facing climate variability.

Challenges and Limitations

High Initial Cost: Commercial systems require significant investment in equipment, sensors, computerized controls, LED lights, and climate management often hundreds of thousands of dollars, making it inaccessible to small-scale farmers.

Technical Complexity: Systems require skilled operators trained in equipment maintenance, nutrient chemistry, sensor calibration, and computerized management. Technical expertise and consistent monitoring are essential.

Equipment Vulnerability: System failures pump breakdowns, clogged nozzles, power outages, sensor malfunctions can result in complete crop loss within hours as roots rapidly dry out. Dependence on electricity is problematic in regions with unreliable power grids.

Disease Spread Risk: Waterborne pathogens in the shared nutrient solution can rapidly spread to entire crops, unlike isolated soil-based farming.

Limited Crop Variety: While excellent for leafy greens, herbs, tomatoes, and peppers, aeroponics is less suitable for grains, root vegetables, and large plants with extensive root systems, limiting its universality.

Real-World Applications

Crops and Uses: Aeroponics is successfully cultivating:

- ✓ Leafy vegetables (lettuce, spinach, kale) reaching market maturity in 3-4 weeks
- ✓ High-value herbs (basil, cilantro, parsley) with 1-2 week cycles
- ✓ Fruiting vegetables (tomatoes, cucumbers, peppers) with excellent yields
- ✓ Seed potato production one of aeroponics' most successful commercial applications
- ✓ Microgreens with extremely high value and rapid turnover

Urban Vertical Farming: Urban vertical farms are bringing fresh produce directly to dense city populations, dramatically reducing food miles. Rather than tomatoes traveling 1,500 miles, urban farms deliver produce within hours of harvest at peak freshness. This model works economically because high-value crops command prices justifying operational costs, and farms achieve 10-20 crop cycles annually.

NASA and Space Agriculture: NASA has partnered with aeroponic technology for use aboard space stations, testing systems for long-duration missions. The 'Astro Garden' is being developed to supply fresh vegetables for future Moon and Mars missions. Space-derived technologies are now adapted for Earth applications including remote locations and water-scarce regions.

Pharmaceutical Bio-farming: Aeroponics is used experimentally to grow genetically modified plants for producing pharmaceuticals, enabling a contained environment that prevents environmental contamination and enhances production efficiency

Conclusion

Aeroponics represents a fundamental reimagining of agriculture for an era of resource constraints and climate uncertainty. By eliminating soil dependence, slashing water consumption, accelerating growth, and enabling year-round production, aeroponics addresses multiple interconnected food security challenges. While barriers remain high costs, technical complexity, and limited crop variety these challenges are not insurmountable. As technology advances and costs decline, aeroponics will become increasingly accessible. The future of agriculture likely won't be entirely aeroponic, but instead aeroponics will occupy a crucial niche: enabling production in urban centers, reducing ecosystem pressure, and supplying fresh produce where traditional farming isn't viable. From NASA's space missions to vertical farms in Tokyo and New York, aeroponics is already reshaping food production. As we face the unprecedented challenge of feeding 10 billion people by 2050 while managing climate change, this revolutionary technology offers genuine hope for a more sustainable, food-secure future.

References

Agrotonomy. (2022). Aeroponics: Modern Plant Cultivation Technology. *Agriculture Journal*

PMC. (2021). Aeroponic systems: A unique tool for estimating plant water use. National Center for Biotechnology Information (NCBI).

Envirevo Agritech. Aeroponics: A Comprehensive Guide.

Vertical farms, building a viable indoor farming model for the future. Open Edition, 2019.

Quinoa: The Golden Grain Transforming Global Agriculture and Nutrition

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Introduction

Quinoa (*Chenopodium quinoa* Willd.) is more than just a grain it's a story of resilience, tradition, and modern innovation that spans continents and cultures. Emerging from the ancient soils of the Andean highlands, quinoa was cherished by the Inca civilization for its life-sustaining qualities and spiritual value, forming the heart of indigenous diets for thousands of years. Although its cultivation dwindled under colonial rule, quinoa has made an inspiring comeback, celebrated globally for both its nutritional excellence and cultural heritage so much so that the United Nations honored 2013 as the "International Year of Quinoa". Incredibly, every tiny quinoa seed is packed with complete protein meaning it contains all nine essential amino acids that our bodies can't produce on their own. This rare trait makes quinoa a stand-out choice for vegetarians, vegans, and anyone seeking high-quality nutrition without relying on animal products. On top of this, quinoa offers a rich supply of vitamins, minerals, and potent bioactive compounds, nourishing the body while supporting overall wellbeing. But quinoa's journey doesn't end with nutrition. Today, it's grown in more than 95 countries, thriving in environments from South America's high mountains to the farmlands of North America, Europe, and Asia. Its adaptability means farmers everywhere from smallholders to commercial growers can benefit from its resilience and sustainability. Quinoa's hardy nature allows it to flourish in poor soils and challenging climates, making it a beacon for sustainable agriculture. Quinoa's rapid rise from a sacred Andean crop to a global superfood is changing how we think about food security, dietary health, and sustainable farming. It's a crop that connects ancient wisdom with modern science and in every bite, it offers hope for a healthier, more inclusive, and sustainable future

Cultivation Practices and Methods: Quinoa's adaptability is nothing short of extraordinary, thriving from sea level all the way to high mountain altitudes near 4,000 meters. Unlike common staples such as wheat, rice, or corn, quinoa takes survival in stride whether it's in cool, brisk climates or on farmland that's less than ideal. Even at lower temperatures (around 45-50°F), quinoa seeds sprout reliably, and mature plants shrug off frost as low as -8°C during early growth stages. Farmers appreciate quinoa's flexibility with soil, too. This crop isn't picky it grows well in sandy, low-fertility soils and can handle a wide pH range, from acidic 4.8 up to alkaline 8.5. The plant's remarkable drought tolerance stands out, especially as water scarcity

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worsens in many regions worldwide. Quinoa's water needs are a fraction of rice about 1,000 cubic meters per hectare, compared to rice's thirst for 15,000 cubic meters making it a lifeline crop in arid climates. Much of this resilience is thanks to quinoa's deep, searching roots, which reach down up to 1.5 meters, tapping into moisture hidden far below the surface. In the field, quinoa is usually direct-seeded at shallow depths (1-2 cm), with seeding rates between 5 and 15 kg ha^{-1} based on local conditions. Farmers often adjust row spacing closer rows (30-76 cm apart) help keep weeds at bay, which is important because quinoa is slower to establish than some aggressive weeds.

Nutritional Benefits and Health Impacts: Quinoa's reputation as a nutritional powerhouse is well deserved it's one of the few plant foods that offer all nine essential amino acids needed for optimal health. Just one cup of cooked quinoa delivers around 8 grams of protein, making it a genuine rival to common animal-based foods. This is especially important for those who follow vegetarian or vegan diets, or people in regions where meat and dairy aren't always accessible. One of the standout amino acids in quinoa is lysine an essential building block for tissue repair, immune support, and hormone production. While grains like wheat, rice, and corn are generally low in lysine, quinoa packs in about 59.8-65.1 mg $gram^{-1}$ of protein, filling a critical gap in plant-based nutrition. Even more impressive, the body can use quinoa protein almost as efficiently as milk. Its biological value (BV) is about 83%, right on par with milk (84.5%) and notably higher than soybeans (72.8%), wheat (64%), or rice (64%). For anyone relying primarily on plant foods, quinoa helps meet high-quality protein needs without compromise. A single serving of quinoa delivers impressive amounts of essential vitamins and minerals often lacking in modern diets:

Magnesium (28% of daily value): Critical for energy production, muscle function, and stress management

Iron (15% of daily value): Essential for oxygen transport and preventing anemia

Zinc (18% of daily value): Supports immune function and wound healing

Copper (39% of daily value): Important for collagen formation and energy metabolism

Manganese (51% of daily value): Supports bone health and metabolic function

Folate (19% of daily value): Crucial for DNA synthesis and pregnancy health

Vitamin B (including B_6 and thiamine): Support nervous system function and energy production. Beyond basic nutrition, quinoa contains diverse bioactive compounds that combat disease and support health. The polyphenols in quinoa including quercetin and kaempferol act as antioxidants, neutralizing harmful free radicals that contribute to aging and chronic disease. Darker varieties (black and red quinoa) contain particularly high concentrations of these protective compounds. Research consistently shows that regular quinoa consumption supports cardiovascular health.

The combination of soluble fiber, plant-based omega-3 and omega-6 fatty acids, and polyphenols helps lower LDL cholesterol and triglycerides while maintaining or raising protective HDL cholesterol. The high fiber content (5 grams per cup) promotes satiety and aids weight management both critical for preventing obesity and heart disease. Quinoa is naturally gluten-free, making it safe for the approximately 1-3% of the global population with celiac disease and millions more with gluten sensitivity. Unlike gluten-free substitutes like rice (low in lysine) or corn (incomplete protein), quinoa provides the nutritional density needed to prevent deficiencies in gluten-free diets. For children with celiac disease, quinoa offers a nutritious, palatable alternative to processed gluten-free products that are often high in refined carbohydrates and low in nutrients.

Future Scope and Global Significance: As global temperatures rise and extreme weather becomes more frequent, quinoa offers a beacon of hope for food security. The crop's remarkable tolerance to drought, salinity, and poor soils conditions becoming increasingly common due to climate change positions it as a strategic crop for vulnerable regions. In areas where conventional crops fail, quinoa can maintain productivity, helping ensure stable food supplies for growing populations. The global market for quinoa is projected to reach USD 2 billion by 2032, growing at 8.2% annually. This expansion reflects rising consumer awareness of quinoa's health benefits and growing demand for sustainable, nutrient-dense foods. Beyond grains, quinoa is increasingly incorporated into breakfast cereals, pasta, baked goods, beverages, and even cosmetics and pharmaceuticals. Malnutrition affects over 2 billion people globally, particularly in developing regions dependent on cereal-based diets deficient in complete protein and essential micronutrients. Quinoa's integration into food systems offers a practical solution. Its complete amino acid profile addresses protein-energy malnutrition, while its rich micronutrient content combats widespread deficiencies in iron, zinc, and B vitamins. Research shows that quinoa supplementation in children's diets increases growth markers and improves nutritional status in vulnerable populations. Integration of quinoa into school feeding programs, public nutrition initiatives, and household diets in developing countries could significantly impact childhood development, immune function, and long-term health outcomes.

Conclusion

Quinoa represents far more than a trendy superfood it is a scientifically validated nutritional powerhouse and a practical solution to interconnected global challenges including malnutrition, food insecurity, and climate change. Its exceptional combination of complete protein, balanced amino acids, abundant vitamins and minerals, and disease-fighting bioactive compounds makes it one of nature's most nutrient-dense foods. For individuals, incorporating quinoa into regular diets can support heart health, improve blood sugar control, strengthen gut and immune function, and prevent chronic diseases. For vulnerable populations including children, pregnant women, vegetarians, and those with dietary restrictions, quinoa offers an accessible, affordable source of complete nutrition. For societies and the global food system, quinoa offers resilience in the face of climate change, improved nutritional security in developing regions, and sustainable agricultural practices that minimize environmental impact. As research continues to unveil new health benefits and applications, and as cultivation expands to new regions, quinoa stands poised to play an increasingly significant role in global health, nutrition, and sustainable agriculture.

References

PMC. Quinoa (*Chenopodium quinoa* Willd.): An Overview of the Potentials.... National Center for Biotechnology Information (NCBI), 2020.

Healthline. Quinoa: Nutrition Facts and Health Benefits. Healthline Nutrition, 2018.

PMC. Nutritional and Functional New Perspectives and Potential.... National Center for Biotechnology Information (NCBI), 2023.

Gluten-Free Wheat: A New Trend in Healthy Eating

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Abstract

Gluten-free wheat is becoming a significant innovation for individuals affected by gluten-related disorders and those pursuing healthier diets. The gluten protein, essential for wheat's baking characteristics, causes adverse immune responses in sensitive people, including those with celiac disease and gluten intolerance. Advances in gene-editing technologies, especially CRISPR/Cas9, have enabled the development of low-gluten or gluten-free wheat varieties that maintain essential nutritional quality and baking properties. These developments offer safer dietary alternatives while expanding food choices for those requiring gluten avoidance. Despite challenges in processing and product texture, ongoing research promises improvements in availability, safety, and consumer acceptance. Gluten-free wheat thus represents a major step toward inclusive nutrition and improved quality of life for millions worldwide.

Introduction

Gluten-free wheat is increasingly becoming a promising option for individuals with gluten-related health issues and those pursuing healthier lifestyles. Gluten, a protein complex present in wheat and related grains, contributes to the chewy texture of bread but can trigger adverse reactions in people with celiac disease, wheat allergy, or gluten intolerance. Creating wheat varieties with little to no gluten aims to offer safe consumption alternatives while retaining the nutritional and functional qualities of wheat.

Why Gluten-Free Wheat?

Gluten-related disorders impact millions globally, manifesting as digestive problems, inflamemation and nutrient absorption difficulties. The standard remedy is a strict gluten-free diet that excludes most traditional wheat products. However, gluten-free diets often face challenges such as limited product availability and nutritional gaps. Gluten-free wheat varieties could provide familiar, nutritious food options free from harmful gluten proteins, improving diet adherence and quality of life.

Advances in Developing Gluten-Free Wheat

Biotechnological progress, notably CRISPR/Cas9 gene editing, has enabled precise modification of wheat genes responsible for producing specific gluten proteins known to cause immune reactions. By targeting these genes, scientists have developed wheat strains with drastically reduced gluten content, without compromising important baking properties or grain yield. This advancement holds great promise for producing wheat safe for people with celiac

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disease and gluten sensitivities.

Nutritional and Health Advantages: Gluten-free wheat offers essential nutrients similar to regular wheat, including carbohydrates, dietary fiber, proteins, and important minerals like iron and B vitamins. It widens dietary choices for people with gluten sensitivities while preserving nutritional value. Moreover, even individuals without diagnosed gluten intolerance sometimes report better digestion and general wellbeing when consuming wheat with lowered gluten levels, making this an emerging health trend.

Challenges and Outlook: Complete gluten removal affects the dough's texture and baking quality, requiring innovation in food technology to maintain product appeal. Additionally, extensive safety evaluations are necessary for new gluten-free wheat lines before widespread adoption. As research continues, it is anticipated that gluten-free wheat products will become more affordable and accessible, expanding their acceptance among consumers.

Conclusion

Gluten-free wheat represents a significant step forward in addressing dietary needs related to gluten intolerance while promoting healthier food options for the broader population. Ongoing research and improved public awareness will help establish these novel wheat varieties as valuable elements in both medical diets and general nutrition.

References

Celiac.org. New Wheat Discovery Could Reduce the Impact of Celiac Disease, 2024.

Susana Sánchez-León *et al*. (2024). CRISPR/Cas9-mediated multiplex gene editing of gamma and omega gliadins: paving the way for gliadin-free wheat. *Journal of Experimental Botany*.

ISAAA.org, Gene Editing to Produce Gluten-Free Wheat, September 2024.

Frontiers in Nutrition, CRISPR/Cas9 Gene Editing of Gluten in Wheat to Reduce Immunogenicity, 2020.

The Role of Pollinators in Horticultural Crops

Aditya Kumar Giri, Shivam Singh, Simran and Ankit Singh Bhadauria

Abstract

Pollinators are vital for the production and resilience of horticulture crops. Pollinators transfer pollen between flowers, allowing for fertilization and the development of fruits and seeds. Many vegetable, fruit, nut, and ornamental crops rely on bees and other insects for pollination. Successful and efficient pollination can lead to increased yield, greater weight and size, improved market acceptability, and overall fruit and crop quality. Pollinator populations are declining globally due to numerous factors, including loss of nesting and feeding habitats, increased pesticide exposure, increased monocropping, climate change, and diseases. These declines pose a critical threat to food security and biodiversity. Farmers can improve pollination with habitat management practices, the introduction of managed colonies of bees, decreasing their pesticide use, and developing local outreach programs in their communities. The health and conservation of pollinators should be promoted in order to achieve sustainable goals for horticultural development, ecological balance, and agricultural sustainability.

Introduction

Pollination is an essential process for horticultural crops, and it consists of the transfer of pollen grains from the male organ of the flower to the female organ, which leads to fertilization and the production of fruits and seeds. Many horticultural crops, such as fruit crops, vegetables, nuts, and ornamental crops, require pollinators to achieve this process. While bees are the most effective pollinators, butterflies, flies, beetles, birds, and bats also play a critical role. Pollinators are key contributors to yield and quality of produce. Crops that are well-pollinated are more likely to develop to produce fruit that is larger, heavier, and more palatable, increases the produce's market value. Floral crops such as apples, cucumbers, almonds, and melons are dependent on bees for successful fruit development. In the absence of pollinators to support the fruiting process, crops often produce few, lower quality fruit. There have been declines in pollinator populations in recent years due to various factors, such as habitat loss, pesticides, climate change, and diseases. These declines are a significant barrier to sustainability in horticulture. It is important to understand the value of pollinators, understand practices that safeguard and promote pollinators, with the goal of supporting food security, preserving biodiversity, and creating healthy ecosystems for the

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next generation.

Importance of Pollinators: Pollinators are crucial to the production and productivity of horticultural crops. Through the process of transferring pollen between flowers, pollinators facilitate fertilization and the development of seeds or fruit. This has direct consequences for yield, fruit quality, and profitability. Pollination by animals, particularly insects, contributes to about one third of food production around the globe. Many horticultural crops, including apples, mangoes, almonds, cucumbers, melons, and many more, are dependent upon pollinators. Effective pollination not only increases the number of fruits produced, but pollination can also increase size, shape, color, and taste. Fruits that have been well-pollinated typically have more uniformity and longer shelf-life, both of which contribute to their marketable standards. Pollinators also contribute to biodiversity and stability in ecosystems. Pollinators assist in the sexual reproduction of flowering plants and, in doing so, ensure the stability of plant diversity that acts as food or habitat to other organisms. Their behavior assists in the continued regeneration or reproduction of natural and cultivated plant species. Without pollinators, many horticultural crops would be negatively impacted, both in yield and quality, which could have negative consequences to farmer income and food security. Understanding and recognizing the value of these insects and supporting practices that safeguard pollinators are fundamental to sustainable horticultural production.

Major Pollinators: A large range of animals serve as pollinators for horticultural crops, but insects play the primary role and are the most effective. Among insect pollinators, bees are the most efficient and reliable pollinator. Honeybees (*Apis spp*.) are the most important managed species used for agricultural pollination and they visit many flowers in a short time, making them especially valuable for crops such as apple, almond, citrus, and sunflower.

Bumblebees (*Bombus spp*.) are also important pollinators, particularly in cooler climates and for greenhouse crops such as tomato, pepper, and strawberry. Bumblebees can perform "buzz pollination," enabling them to displace pollen from these flowers while other insect pollinators often have a non-productive visit. There are also solitary bees, like mason bees and leafcutter bees that are important for crops needing pollination in the climate like alfalfa, berries, and various fruits. Unlike honeybees, these solitary bees do not build a colony, but they are powerful pollinators for these crops. In addition to bees, there are also other insects such as butterflies, moths, flies, and beetles that play valuable roles for horticultural products, especially ornamentals and tropical fruits. Although infrequently considered pollinators in fruit production, some birds like hummingbirds and even bats have been reported to pollinate flowers, primarily tropical flowers. All these pollinators contribute to the production of fruit and seed, and are crucial for commercial food production and the environment.

Honeybees (*Apis spp*.): The most widely used managed pollinators in agriculture.

Bumblebees (*Bombus spp*.): Effective in cooler climates and for crops like tomato and pepper grown in greenhouses.

Solitary bees (like leafcutter and mason bees): Important for crops such as alfalfa and certain fruits.

Other insects and animals: Butterflies, flies, beetles, birds, and bats assist in pollinating a range of ornamental and tropical crops.

Threats to Pollinators

Pollinators are under threat from numerous stressors, resulting in a widespread decline in their populations across the globe. One of the leading causes is habitat destruction due to urbanization, deforestation, and agricultural intensification. Pollinators rely on habitat for nesting sites and for availability of flowering plants to feed on, meaning, when habitats are lost, it restricts access to nesting sites and continuous supplies of flowering plants. The use of pesticides is also a major stressor of pollinator populations. Insecticides can be toxic to bees and other beneficial insects, especially insecticides containing neonicotinoids. Even low doses can inhibit pollinators' ability to navigate, forage, and reproduce. Additionally, the practice of monocropping and the lack of crop diversity limits both the number of diverse flowering species and the quality of nutrition available for pollinators. Climate change is also amplifying these stressors by altering flowering seasons and altering weather conditions. Extreme heat, drought, and heavy rain can alter the timing of both pollinator activity and flower availability. Diseases and parasites, including the Varroa mite that infects honeybees, further stress pollinator health by weakening colonies and increasing mortality in general. The cumulative result of these stressors is a threat to both pollinator species and, for example, horticultural crop production that relies on pollinators. It is important to protect pollinators so that they will be able to thrive and contribute to a healthy ecosystem and the sustainability of food production employment opportunities

Enhancing Pollination in Horticulture

Enhancing pollination in horticultural crops is essential for increased yield and quality. In addition, there are a variety of actions farmers can take in a practical manner to help promote and enhance pollinator services both in their fields and orchards. One of the best ways to enhance pollinator services is to develop and improve habitats that provide protection, nesting habitats, and wildflowers with blooms for the entire growing season. Strategic planting of primitive flowering species around the field perimeter or within an orchard creates continuous food resources for pollinators across the growing season. During the flowering cycle of crops, controlled bee colonies (i.e., honeybees, bumblebees) can be introduced to the farm to enhance pollination services. In greenhouses, bumblebees can be especially effective because they can work in cooler temperatures and low-light conditions. Minimizing pesticides whenever possible, and utilizing integrated pest management and integrated management for pollinators will promote both the health of crops and bee colonies along with being interdisciplinary approaches between pests and pollinators. Protection of the pollinator populations is also enhanced by educating growers, and their communities about the valued role of pollinators on the farm. Maintaining healthy populations of pollinators while developing sustainable strategies will enhance food security, improve sustainability of horticultural systems, and ensure that we have the supply of environmental resources needed for growing healthy and high-quality crops.

Farmers can improve pollination by

- ✓ Providing nesting sites and floral resources for native pollinators.
- ✓ Introducing managed bee colonies during flowering periods.
- ✓ Avoiding pesticide use during bloom.
- ✓ Maintaining diverse flowering plants around crop fields.

Conclusion

Pollinators are key partners in horticultural production with a direct impact on the quality and amount of crops. They play a role that goes beyond increasing yield to managing the balance of the ecosystem and promoting biodiversity. Declines in pollinator populations impact not only agricultural productivity but also ecosystem stability, agriculture-based livelihoods, and the potential for greater ecosystem degradation. Protecting and enhancing pollinator activity is essential to a resurgence of productive horticultural crops and a more sustainable agricultural system for generations to come. Such practices will include the restoration of a natural habitat, integrated pest management, or introduction of managed pollinators.

References

Aizen, Marcelo, A. and Lawrence, D. Harder. (2009). The Global Stock of Domesticated Honey Bees is Growing Slower than Agricultural Demand for Pollination. *Current Biology*, 19(11): 915-918.

Gallai, Nicola, Jean-Michel Salles, Josef Settele and Bernard E. Vaissière. (2009). Economic Valuation of the Vulnerability of World Agriculture Confronted with Pollinator Decline. *Ecological Economics*, 68(3): 810-821.

Klein, Alexandra-Maria, *et al*. (2007). Importance of Pollinators in Changing Landscapes for World Crops. *Proceedings of the Royal Society B: Biological Sciences*, 274(1608): 303-313.

Potts, Simon G., *et al*. (2010). Global Pollinator Declines: Trends, Impacts and Drivers. *Trends in Ecology & Evolution*, 25(6): 345-353.

Free, John B. (1993). *Insect Pollination of Crops*. Academic Press, 1993.

Kevan, Peter G., and V. L. Imperatriz-Fonseca, editors. (2002). Pollinating Bees: The Conservation link Between Agriculture and Nature. Ministry of Environment, Brasília.

Role of Germplasm Collection and Conservation in Plant Breeding

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Abstract

Germplasm collection and conservation play a vital role in sustaining agricultural biodiversity and supporting the development of improved plant varieties through plant breeding. Germplasm refers to the hereditary material preserved in seeds, tissues, or DNA of plant species, which serves as a valuable resource for breeding programs. With the increasing challenges of climate change, pest outbreaks, and diminishing genetic diversity due to modern farming practices, the need to safeguard and utilize diverse plant genetic resources has become more important than ever. This article explores the concept of germplasm, the necessity of its collection, and various conservation methods including in-situ and ex-situ techniques such as seed banks and gene banks. It also highlights how plant breeders use these genetic materials to introduce desirable traits like disease resistance, drought tolerance, and enhanced yield into new crop varieties. Furthermore, the article discusses current challenges in germplasm management and emphasizes the importance of advanced technologies like molecular markers and gene editing tools in improving conservation efforts.

What is Germplasm?

Germplasm refers to the genetic material of plants that is used for reproduction and breeding. It includes seeds, tissues, or any living part of a plant that carries the genes necessary to grow a new plant. Germplasm is collected and preserved because it contains valuable traits like resistance to diseases, tolerance to drought, or high yield, which plant breeders can use to develop improved crop varieties.

Need for Germplasm Collection

- ✓ The collection of germplasm is essential for preserving the genetic diversity of plants, which is the foundation for crop improvement and food security. Modern agriculture and climate change are causing the loss of many traditional plant varieties. Once lost, their unique traits such as drought tolerance, pest resistance, or nutritional value cannot be recovered.
- ✓ Plant breeders need access to a wide range of genetic material to develop new varieties that can survive in changing environments, fight new diseases, and meet the growing food demands of the population. Germplasm collection ensures that these valuable genes are not lost and are available for current and future breeding programs.
- ✓ It also supports scientific research, helps maintain ecosystem stability, and ensures the

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survival of rare or endangered plant species. Without proper germplasm collection and conservation, the world may face a serious decline in crop productivity and resilience.

Methods of Germplasm Collection

Germplasm collection methods refer to the different ways in which plant genetic materials are identified, collected, and preserved for future use in plant breeding and conservation. There are two main methods:

In-situ Collection

- ✓ "In-situ" means on-site collecting and conserving germplasm in its natural habitat.
- ✓ Plants are preserved where they naturally grow like forests, farms, or wild areas.
- ✓ Example: Traditional crop varieties grown in tribal villages.
- ✓ Advantage: Continuous natural evolution and adaptation.

Ex-situ Collection

- ✓ "Ex-situ" means off-site collecting germplasm and storing it in controlled environments.
- ✓ Types include:
  - **Seed banks:** Store seeds at low temperature.
  - **Field gene banks:** Live plants grown in special farms.
  - **Tissue culture repositories:** Plant parts stored in labs.
  - **Cryopreservation:** Deep freezing tissues or cells.

Advantage: Long-term safety and easier access for research and breeding.

Example: Potato Plant Collection

Conservation Stratergies: Germplasm conservation strategies are the different methods used to store and protect plant genetic resources for long-term use in plant breeding, research, and food security. These strategies ensure that the genetic diversity of crops is not lost due to climate change, urbanization, or modern farming.

There are two major strategies:

In-situ Conservation

Definition: Conservation of plants in their natural habitat or original ecosystem. It allows natural evolution and adaptation.

Example

- ✓ Protected forest areas.
- ✓ On-farm conservation of traditional varieties.

Advantage: Plants adapt to environment over time, more dynamic.

Ex-situ Conservation

Definition: Conservation of germplasm outside its natural habitat in controlled conditions.

- ✓ Used for long-term storage and easy access.
- ✓ Example:
  - Seed banks
  - Gene banks
  - Cryopreservation (ultra-cold storage)
  - Tissue culture labs

Advantage: Safe from environmental threats, available anytime for breeding.

Role in Plant Breeding

Germplasm plays a fundamental role in plant breeding. It provides the raw genetic material needed to develop new and improved crop varieties. These genetic resources contain valuable traits such as:

- ✓ High yield
- ✓ Resistance to diseases and pests
- ✓ Tolerance to drought, salinity, or temperature extremes
- ✓ Better nutritional quality
- ✓ Early maturity

Plant breeders select desirable traits from different types of germplasm including traditional varieties, wild relatives, and modern cultivars and combine them through hybridization and genetic techniques to create superior crop varieties. Without diverse germplasm, plant breeders would not have enough variation to choose from. This would limit the ability to respond to challenges like climate change, new diseases, or food demand.

Example:

- ✓ The famous IR8 rice (Miracle Rice) was developed using wild rice germplasm for high yield.
- ✓ Many hybrid maize and drought-resistant wheat varieties were made using genes from collected germplasm.

Challenges

Genetic Erosion

- ✓ Loss of traditional crop varieties due to modern farming.
- ✓ Once lost, their unique traits (like drought resistance) cannot be recovered.

Lack of Awareness

- ✓ Many farmers and communities do not know the value of traditional seeds and local varieties.
- ✓ This leads to reduced collection and on-farm conservation.

Financial and Infrastructure Limitations

- ✓ Gene banks, cold storage, and tissue culture labs require high costs for operation and maintenance.
- ✓ Many developing countries face budget constraints.

Technological Limitations

- ✓ Some plant species (like recalcitrant seeds) cannot be stored easily using traditional methods.
- ✓ Need advanced technology for long-term conservation (e.g., cryopreservation).

Data Management and Accessibility

- ✓ Poor digital record-keeping or lack of databases makes it difficult to track, share, and utilize germplasm effectively.

Legal and Policy Issues

- ✓ Some international policies restrict the exchange of germplasm across borders.

- ✓ This limits access to global plant genetic diversity.

Advantages in Germplasm Conservation

- ✓ Preservation of Genetic Diversity
- ✓ Conserves different genes and traits of various plant species.

Foundation for Crop Improvement

Provides useful genes for breeding new crop varieties with:

- ✓ Higher yield
- ✓ Pest and disease resistance
- ✓ Drought and flood tolerance

Support for Food Security

- ✓ Ensures the availability of plant genetic resources to meet future food demands.
- ✓ Helps adapt crops to changing climate conditions.

Protection from Genetic Erosion

- ✓ Prevents the permanent loss of valuable plant traits due to modernization, habitat loss, or overuse of hybrids.

Research and Education

- ✓ Acts as a resource for plant scientists, students, and researchers.
- ✓ Supports studies on evolution, genetics, and conservation.

International Collaboration

- ✓ Enables the sharing of genetic material between countries for global food solutions.

Conclusion

Germplasm collection and conservation are fundamental pillars of sustainable agriculture and crop improvement. By preserving the genetic diversity of plants, we ensure the continued availability of valuable traits necessary for plant breeding, especially in the face of climate change, emerging diseases, and food security challenges. In-situ and ex-situ conservation strategies offer effective ways to protect and utilize plant genetic resources. With advancements in technology and international cooperation, germplasm conservation not only supports present-day breeding programs but also secures the future of global agriculture. Hence, it is essential to invest in and promote germplasm conservation as a long-term solution for sustainable food systems and biodiversity preservation.

References

FAO (Food and Agriculture Organization). (2010). The Second Report on the State of the World's Plant Genetic Resources for Food and Agriculture. FAO, Rome.

Singh, B. D. (2019). Plant Breeding: Principles and Methods (11^{th} ed.). Kalyani Publishers.

Sharma, J. R. (1994). Principles and Practice of Plant Breeding. Tata McGraw Hill.

Indian Council of Agricultural Research (ICAR). (2022). National Bureau of Plant Genetic Resources (NBPGR) Annual Report.

Frankel, O. H. and Bennett, E. (1970). Genetic Resources in Plants their Exploration and Conservation. Blackwell Scientific Publicat-ions.

Good Agricultural Practices for Turmeric

Sunita Yadav, Suresh Kumar Jat and Yougendra Singh

Turmeric (*Curcuma longa* L), the ancient and sacred spice of India known as 'Indian saffron' is used as condiment, dye, drug and cosmetic in addition to its use in religious ceremonies. Turmeric enjoys a unique distinction among spices due to its various medicinal properties and versatility. The spice played a great role in the life of ancient people as a wound healer, stomach ache, flatulence etc but in recent times it has anti cancer and anti viral activities and hence finds use in the drug industry and cosmetic industry. India is a leading producer and exporter of turmeric in the world. The states of Telangana, Maharashtra, Tamil Nadu, and Andhra Pradesh together contributes 63.4% of India's turmeric production. Turmeric is the dried rhizome, plant is propagated from rhizomes. The leaves are long, broad, lanceolate and bright green. The flowers are pale yellow and borne on dense spikes. The pseudostems are shorter than leaves. The rhizomes are ready for harvesting in about 7 to 9 months after planting.

Climate and soil: Turmeric requires a warm and humid climate. It can be grown in diverse tropical conditions from sea level to 1500 m above sea level, at a temperature range of 20-35°C with an annual rainfall of 1500 mm or more, under rainfed or irrigated conditions. Though turmeric thrives in different types of soil ranging from light black loam, red soils to clayey loams, rich loamy soils with a pH range of 4.5-7.5 having natural drainage and irrigation facilities are the best. Turmeric cannot stand water stagnation or alkalinity.

Land preparation: It is possible to use minimum tillage techniques when preparing the land. It is possible to prepare beds that are 15 cm high, 1 m wide, and a reasonable length with a minimum of 50 cm between them. The rhizomes are planted in shallow trenches on top of the ridges and furrows that have been prepared for the irrigated crop. The typical spacing is 15-20 cm between plants and 45-60 cm between ridges. Beds that are solarized help prevent the growth of organisms that cause diseases and pests. The polythene sheets used for soil solarisation should be kept away safely after the work is completed.

Light soils: Beds of 1.0 m width, 30 cm height and of convenient length are prepared with spacing of 50 cm between beds. Rhizomes are planted at 25 cm x 30 cm.

Loamy soils: Flat beds of 3 x 1.8 m size are prepared

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providing necessary irrigation channels. Rhizomes are dibbled at 15 cm apart in the plough furrows spaced 30 cm apart.

Heavy soils: Ridges and furrow system is adopted and rhizomes are sown at 15 to 20 cm spacing. Spacing between ridges is maintained at 45 to 60 cm.

Varieties: Suvarna, Suguna, Sudarsana, IISR Prabha, IISR Prathibha, IISR Pragati developed by Indian Institute of Spices Research, Kozhikode.

Planting material: Carefully preserved seed rhizomes free from pests and diseases which are collected from cultivated farms should be used for planting. A seed rate of 20-25 qt. of rhizomes is required for planting one hectare of turmeric. For sowing, both the mother - rhizomes and fingers are used. The fingers are cut into 4-5 cm long pieces, and the mother rhizomes are planted as such or split into two; each having at least one sound bud. The seed rhizomes are to be treated with mancozeb 0.3% (3 g L^{-1} of water) for 30 min, shade dried for 3-4 hr. and planted or seed are treated with *P flourescens* (10 g kg^{-1}) and *T. harzianum* (4 g kg^{-1}) and then sown.

Transplantting:

Pro-tray technology

- ✓ Select well grown, healthy rhizomes and treat with Carbendazim @ 2 g L^{-1} + monocrotophos @ 1.5 mL L^{-1} and then cut into single bud.
- ✓ Cover these buds with cocopeat and spray with humic acid (0.5%).
- ✓ Place the sprout single bud in pro tray, which is filled with cocopit @ 100 g mixed with *P flourescens* @ 1 g and cover with polythene for seven days
- ✓ After sprouting, remove the polythene sheets and keep in 50% shade.
- ✓ Spray humic acid (0.5%) after the emergence of leaf.
- ✓ Seedlings will be ready for transplanting on 30-35 days.

Planting:

Different planting methods

Flat bed method: Planting is done by dibbling rhizome in furrows behind the country plough. The seeds are then covered with loose soil from the ridge. The spacing is 30 x 15 cm. This method has the more chances of occurrence of pest and diseases. Flooding method of irrigation is adopted.

Ridges and Furrow method: In this method, ridges and furrows are prepared with tractor with a spacing of 45x20 cm.

Raised bed method: In this method, raised bed with 1m width and 30 cm height is prepared. The spacing between beds is 30 cm. Four rows with spacing of 30 x 15 cm is recommended with one drip line in lengthwise at the centre.

Manuring and fertilizer: Application of well rotten cow dung or compost from own farm @ 2-3 t $acre^{-1}$ may be given as basal dose while planting rhizomes in the pits. In addition, application of neem cake @ 0.8 t $acre^{-1}$ is also desirable.The fertilizers are to be applied in 2-3 split doses. Full dose of phosphorus is applied as basal at the time of planting. Equal split doses of N and K is top dressed at 45, 90 (and 120) DAP.

Micronutrient application: Micronutrient application is imperative for enhanced yield. Apply 375 g each of Boron, Iron and Zinc, at rhizome development stage, as Borax, Ferrous sulphate, Zinc sulphate + 375 g of Urea in 250 lit of water ha^{-1}. Spray twice at 25 days interval.

Cultural practices: The crop is to be mulched immediately after planting with green leaves @ 12-15 t ha^{-1}. Mulching may be repeated @ 7.5 t ha^{-1} at 40 and 90 days after planting after weeding, application of fertilizers and earthing up. Normally, this operation is done in rainfed areas particularly in high rainfall regions and slope land.Weeding has to be done thrice at 60, 90 and 120 days after planting or depending upon weed intensity. Pre emerge application of Pendimetalin 1 kg ha^{-1} or Oxyfluorfen @ 0.12 kg ha^{-1} keeps the weeds away for 3-4 weeks from sowing. Post-emergence application of quizalofop ethyl @ 0.05 kg ha^{-1} gives good control. In the case of irrigated crop, depending upon the weather and the soil conditions, about 15 to 23 irrigations are to be given in clayey soils and 40 irrigations in sandy loams in conventional system of irrigation. Drip irrigation daily or alternate day also useful.

Cropping systems: Turmeric is a long duration crop (9 months) in which a short duration crop can be cultivated as an inter crop to get a supplementary income before the main crop is harvested. Inter-cropping turmeric with small onion and mulching appreciably increased the fresh rhizome yield. Turmeric grown with chillies as a border crop gave a maximum yield with additional chilli yield. Mixed cropping can be adopted with redgram, sunhemp, chillies, colocasia, onion, brinjal and cereals like maize and ragi.

Plant protection

Diseases

Leaf Blotch: *Taphrina maculens*

Leaf Spot: Leaf spot is caused by *Colletotrichum capsici*

Leaf blight: *Rhizoctonia solani*

Rhizome rot: *Pythium aphanidermatum*

Management

- ✓ Spray with mancozeb 0.2% or copper oxy chloride 0.25% or propiconazole 0.1% at fortnight intervals for control of leaf blotch, leaf spot and leaf blight.
- ✓ For rhizome rot bed should be drenched with copper oxychloride 0.25% or metalaxyl - mancozeb 0.125%. Rhizome treatment with mancozeb 0.3% or copper oxychloride 0.25% for 30 minutes before planting.

Insect pests

Shoot borer: *Conogethes punctiferalis*

Rhizome scale: *Aspidiella hartii*

Thrips: *Panchaetothgrips indicus*

Management

- ✓ Use of blue sticky trap @ 15-20 ha^{-1}.
- ✓ Raking the soil for expose pupae and killing them.
- ✓ Spray NSKE @ 5% along with sticking agent.
- ✓ Conserve natural enemies.
- ✓ Spray two times of carbary .01% or *Bacillus*

thuringiensis 0.1% or NSKE 5% along with sticking agent or phosalone 0.05% or malathion 0.1% in alternation at 20 days interval.

- ✓ Spray thiamethoxam 25 WG @ 200 g or imidacloprid 17.8 SL @ 200 ml or diamethoate 30 EC @ 1.0 lit or malathion 50 EC 1.0 litre in 500 litre water ha^{-1}.

Harvesting and curing: The crop has to be harvested at the right maturity and is ready for harvesting in about 7 to 9 months after sowing depending upon the variety. Usually the land is ploughed and the rhizomes are gathered by hand picking or the clumps are carefully lifted with a spade. Harvested rhizomes are cleaned of mud and other extraneous matter adhering to them. The average yield $acre^{-1}$ is 8-10 tonnes of green turmeric. Curing involves boiling of rhizomes in fresh water and drying it in the sun. No chemical should be used for processing. The cleaned rhizomes are boiled in copper or galvanized iron or earthen vessels, with water just enough to soak them. Boil till the fingers/mother rhizomes become soft. The cooked turmeric is taken out of the pan by lifting the troughs and draining the water into the pan itself. The same hot water in the pan can be used for boiling the next lot of raw turmeric which is already filled in the troughs. Alternatively, rhizomes may also be cooked using baskets with perforated bottom and sides. The mother rhizomes and the fingers are cured separately. The cooking of turmeric is to be done within 2-3 days after harvest. The cooked fingers/mother rhizomes are spread on bamboo mats or cement floor under the sun for drying. The rhizomes are spread in 5-7 cm thick layers for desirable colour of the dried product. During night time the material should be heaped or covered. It may take 10-15 days for the rhizomes to become completely dry. Artificial drying using cross-flow hot air at a maximum temperature of 60°C is also found to give a satisfactory product. In the case of sliced turmeric, artificial drying has a clear advantage giving brighter coloured product than sun drying which tends to suffer from surface bleaching. The recovery of dry product varies from 20-25% depending upon the variety and the location where the crop is grown. Dried turmeric has a poor appearance and rough dull colour outside the surface with scales and root bits. Smoothening and polishing the outer surface by manual or mechanical rubbing improves the appearance. Manual polishing consists of rubbing the dried turmeric fingers on a hard surface. The improved method is by using hand-operated barrel or drum mounted on a central axis, the sides of which are made of expanded metal mesh. When the drum filled with turmeric is rotated, polishing is effected by abrasion of the surface against the mesh as well as by mutual rubbing against each other as they roll inside the drum. The turmeric is also polished in power-operated drums. The colour of the turmeric always attracts the buyers. In order to impart attractive yellow colour, turmeric suspension in water is added to the polishing drum in the last 10 minutes. When the rhizomes are uniformly coated with suspension they may be dried in the sun.

Yield: The yield of pure crop varies from 8000 to

10000 kg acre^{-1}. Under exceptionally favourable conditions, viz. abundant manuring and copious irrigation it may be as high as 12000 kg acre^{-1}.

Health benefits of turmeric in our daily life

- ✓ It is a natural antiseptic and antibacterial agent, useful in disinfecting cuts and burns.
- ✓ When combined with cauliflower, it has shown to prevent prostate cancer and stop the growth of existing prostate cancer.
- ✓ Prevented breast cancer from spreading to the lungs in mice.
- ✓ May prevent melanoma and cause existing melanoma cells to commit suicide.
- ✓ Reduces the risk of childhood leukemia.
- ✓ Is a natural liver detoxifier.
- ✓ May prevent and slow the progression of Alzheimer's disease by removing amyloyd plaque buildup in the brain.
- ✓ May prevent metastases from occurring in many different forms of cancer.
- ✓ It is a potent natural anti-inflammatory that works as well as many anti-inflammatory drugs but without the side effects.
- ✓ Has shown promise in slowing the progression of multiple sclerosis in mice.
- ✓ Is a natural painkiller and cox-2 inhibitor.
- ✓ May aid in fat metabolism and help in weight management.
- ✓ Has long been used in Chinese medicine as a treatment for depression.
- ✓ Because of its anti-inflammatory properties, it is a natural treatment for arthritis and rheumatoid arthritis.
- ✓ Boosts the effects of chemo drug paclitaxel and reduces its side effects.
- ✓ Promising studies are underway on the effects of turmeric on pancreatic cancer.
- ✓ Studies are ongoing in the positive effects of turmeric on multiple myeloma.
- ✓ Has been shown to stop the growth of new blood vessels in tumors.
- ✓ Speeds up wound healing and assists in remodeling of damaged skin.
- ✓ May help in the treatment of psoriasis and other inflammatory skin conditions.

References

Lohar, R. and Hase, C. (2021). Sustainable agricultural practices for improving growth, yield and quality of turmeric (*Curcuma longa* L.). *Annals of Plant and Soil Research*, 23(1): 48-53.

Dayal, G., Singh, S. and Pahade, E. (2023). Organic cultivation of turmeric by Good Agricultural Practices (GAP) in Bundelkhand region.

Singh, M., Bairwa, D. K., Dadrwal, B. K. and Chauhan, J. (2019). Relative efficacy of new generation insecticides against sucking insect pests of green gram. *Journal of Pharma-cognosy and Phytochemistry*, 8(2): 882-886.

Singh, M., Bairwa, D. K., Dadrwal, B. K. and Chauhan, J. (2019). Screening of green gram genotypes for resistance against sucking insect pests. *Journal of Pharmacognosy and Phytochemistry*, 8(2): 933-938.

Plant Breeding and Genetic Innovations for Food Security

Mahendra Kumar Seemar, Saroj and Rohit Sharma

Introduction

Food security means ensuring that every person has access to sufficient, safe, and nutritious food. With the world's population expected to cross 9-10 billion by 2050, agriculture faces challenges like climate change, water scarcity, pests, and shrinking farmland. Plant breeding and modern genetic innovations are powerful tools to meet these challenges.

What is Plant Breeding?

Plant breeding is the science of improving crops by selecting or creating varieties with desirable traits such as high yield, disease resistance, and better nutritional quality. Traditional farmers practiced selection for thousands of years, but scientific breeding began after the discovery of Mendel's laws of inheritance.

Conventional Methods

Selection: Choosing the best plants to reproduce.

Hybridization: Crossing two parents to combine good traits.

Mutation Breeding: Using radiation/chemicals to create useful variations.

Modern Innovations

Molecular Breeding & Marker-Assisted Selection (MAS): Using DNA markers to identify and transfer traits faster.

Genetic Engineering: Inserting genes (e.g., *Bt* cotton) to improve pest resistance.

Genome Editing (CRISPR): Precisely editing plant DNA for desired traits like drought tolerance or nutrient enrichment.

Breeding for Climate and Nutrition

- ✓ Crops are being bred for drought, heat, and salt tolerance to survive harsh climates.
- ✓ Biofortified crops (e.g., Golden Rice with Vitamin A, Zinc-rich wheat, Iron-rich beans) improve nutrition and fight malnutrition.

Case Studies

IR8 Rice (Miracle Rice): Helped boost food production during the Green Revolution.

***Bt* Cotton in India:** Reduced pesticide use and increased yield.

Drought-Tolerant Maize in Africa: Secured production in dry regions.

Breeding for Stress Resistance

Climate change has made stress tolerance critical. Breeding programs now focus on:

- ✓ Drought-resistant crops (maize, sorghum)
- ✓ Heat-tolerant wheat and rice
- ✓ Salt-tolerant rice (e.g., IRRI's "Swarna Sub1")
- ✓ Flood-resistant varieties for regions with heavy monsoons. Such innovations help farmers maintain stable yields despite harsh conditions.

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Breeding for Nutritional Security

Nutrition is as important as yield. Millions suffer from hidden hunger (micronutrient deficiencies). Breeding addresses this through biofortification:

Golden Rice: Vitamin A-rich rice to fight blindness and malnutrition.

Zinc-rich wheat: HarvestPlus program.

Iron-rich beans: Anemia reduction.

Quality Protein Maize (QPM): Enriched with lysine and tryptophan.

Plant Breeding in Climate-Smart Agriculture

Plant breeding supports climate-smart practices by:

- ✓ Developing short-duration varieties that escape drought or floods.
- ✓ Increasing nitrogen-use efficiency, reducing fertilizer dependence.
- ✓ Enhancing carbon sequestration by deep-rooted crops.

Issues and Concerns

While innovations bring benefits, there are concerns about GM crops, biodiversity loss, corporate control of seeds, and farmer dependence on companies. Public awareness and ethical use of technology are important.

Future Outlook

The future of breeding will involve AI, big data, and digital tools to speed up research. With climate-smart and sustainable practices, plant breeding will remain the backbone of ensuring global food security.

Ethical, Social, and Environmental Issues

GM Crop Safety: Concerns over health and ecological impacts.

Biodiversity Loss: Risk of dependence on a few high-yield varieties.

Corporate Control: Patents on seeds restrict farmer freedom.

Public Perception: Lack of awareness fuels resistance to GM foods.

Conclusion

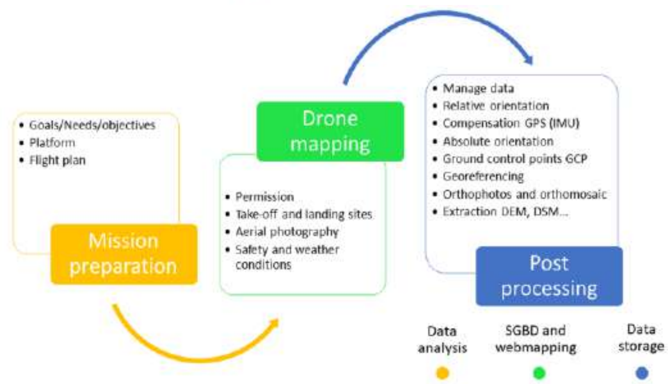
Plant breeding and genetic innovations are essential to feed a growing world population. By combining traditional knowledge with modern science, we can ensure that agriculture remains productive, resilient, and sustainable.

Drones in the Field: A New Era of Precision Farming in India

Deep G. Kachot, Udaysinh B. Jadav, Jenish D. Dholariya, Badal K. Koyani and Kevalkumar F. Vadadodiya

Introduction

The Indian agriculture sector, largely dominated by small and marginal farmers, is undergoing a silent technological revolution. Among the most promising innovations transforming farming practices is the use of drones formally known as Unmanned Aerial Vehicles (UAVs). What was once viewed as futuristic or suitable only for the defense sector is now being used by farmers to monitor crops, spray pesticides, survey fields, and assess damage. In the current age of climate change, rising costs, and growing demand for sustainable agriculture, drones have emerged as a solution to multiple problems lack of skilled labor, inefficient input use, and delayed decision-making. However, the adoption of drone technology among Indian farmers remains limited. This is where Agricultural Extension Education becomes a game-changer. Extension professionals can act as catalysts in making drone-based agriculture inclusive, accessible, and effective across India's diverse agricultural landscapes. In recent years, agriculture has been undergoing a technological transformation that is reshaping the way we grow, manage, and harvest crops. At the forefront of this transformation is precision farming, a modern agricultural practice that uses advanced technology to optimize crop production and resource management. Among the most innovative tools in precision farming are AI-driven drones, which are revolutionizing the agricultural landscape by providing farmers with unprecedented levels of insight and control over their fields.



What are Agricultural Drones?

Agricultural drones are remotely operated flying devices equipped with sensors, cameras, and spraying equipment. Their major uses include:

- ✓ Aerial imaging and crop monitoring.
- ✓ Precision spraying of fertilizers and pesticides.
- ✓ Mapping soil and water variability.
- ✓ Assessing plant health using multispectral and thermal imagery.

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Requirements for drone flying under the old Indian policy

Category	Unique Identification Number (UIN)	Operator Permits	Estimated Approval Time	Height Allowed to Fly	Local Police Permission	Flight Plan and ADC
Nano drones	No	Yes	Not Required	50 feet	Yes	No
Microdrones	Yes	Yes	2-7 days	200 feet	Yes	No
Small drones and above	Yes	Yes	2-7 days	200-400 feet	Yes	Yes

- ✓ Estimating crop yields and damage post-disasters
- ✓ These capabilities allow farmers to save time, labor, and resources while making data-driven decisions.

Drone classification in India by weight

Nano drones: Weighing up to 250 g

Micro drones: Weighing 0.25 kg to 2 kg

Small drones: Weighing 2 kg to 25 kg

Medium drones: Weighing 25 kg to 150 kg

Large drones: Weighing more than 150 kg

Classification of Drones Used in Agriculture

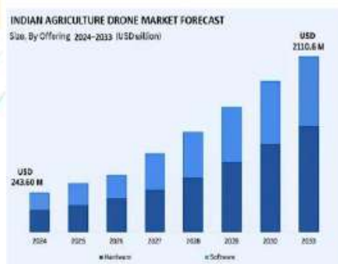
Agricultural drones can be categorized into several classes based on their design and operational mode:

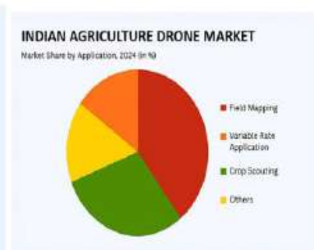
Fixed-wing Drones: These aircraft-like drones are engineered to cover extensive areas. Their capacity to operate at high altitudes enables the capture of high-resolution images over vast agricultural zones. They are particularly efficacious for large-scale mapping and surveillance missions.

Multirotor Drones: Multirotor drones, such as quadcopters, offer enhanced maneuverability and hovering capabilities. They are optimal for applications requiring high precision, such as targeted spraying and detailed crop inspection. Their vertical take-off and landing capabilities make them suitable for use in challenging terrain.

Hybrid Drones: The term "hybrid" in this context refers to drones that combine the features of both fixed-wing and multirotor platforms. These drones enable vertical take-off and landing while providing extended flight endurance. They are particularly advantageous for missions necessitating both extensive coverage and high precision.

Foldable-wing Drones: These innovative drones offer enhanced portability while maintaining performance comparable to fixed-wing drones. They are designed for easy transportation and field deployment, making them particularly suitable for small- and medium-scale agricultural operations.





Drone Usage in Indian Agriculture: Current Trends

Drone Spraying Services: Drones can spray fertilizers or pesticides over 1 hectare in just 8-10 minutes. This is especially helpful in tall crops like sugarcane, paddy, and maize, where manual spraying is laborious, hazardous, and inefficient.

Real-time Crop Monitoring: Drones equipped with NDVI sensors detect plant stress, nutrient deficiencies or pest attacks early. Farmers can target interventions precisely instead of blanket applicationions.

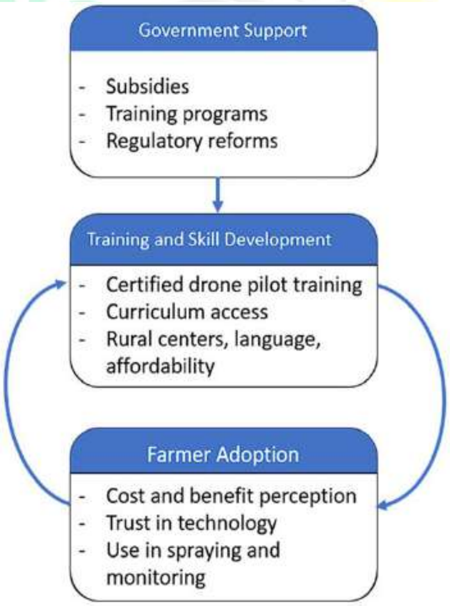
Disaster Assessment: After floods or hailstorms, drones help authorities assess damage quickly and fairly essential for crop insurance claims and relief decisions.

Digital Mapping for Precision Farming: Drones generate high-resolution field maps, helping farmers understand soil variability and plan input application zones accordingly.

Government Support and Policy Push

Recognizing the potential of drones in agriculture, the Government of India has launched several initiatives:

Sub-Mission on Agricultural Mechanization (SMAM): Offers subsidies to FPOs and Custom Hiring Centers (CHCs) for drone procurement.



Drone Rules 2021: Eased restrictions for drone operations in agriculture and removed several licensing requirements.

Digital Agriculture Mission (2021-2025): Drones are a key component for digitizing Indian agriculture. As of 2025, the government provides up to 100% subsidy on drone purchase to select ICAR institutes, KVKs, and SAUs for demonstration purposes, and up to 40% for FPOs and agri-entrepreneurs.

Challenges in Drone Adoption

High Initial Cost: Agricultural drones cost between ₹5-10 lakhs, which is unaffordable for most individual farmers.

Lack of Trained Operators: Operating drones requires training, especially for spraying applications to avoid overuse or drift.

Battery and Repair Issues: Frequent charging, low flight duration, and limited service centers hinder usage.

Legal and Regulatory Confusion: Despite relaxed norms, confusion persists about pilot licenses, flight permissions, and drone insurance.

Fear of Technology: Farmers may fear drone malfunction, spraying errors, or losing control this hinders first-time use.

Future Scope: Integrating Drones with Other Technologies

Drones + AI: Drones can be equipped with AI cameras to:

- ✓ Detect pests before visible symptoms
- ✓ Estimate yield via image analytics
- ✓ Suggest need-based spraying areas

Drones + Climate Resilience: Extension workers can use drones to monitor climate stress (drought, heat) and suggest adaptive practices such as alternate crops, staggered sowing, and micro-irrigation.

Drones + Crop Insurance: Drone images can serve as credible evidence for yield loss and be linked with

PMFBY crop insurance claims minimizing farmer harassment and dispute.

Conclusion

Precision farming using AI drones is not just a technological advancement; it is a game changer for the agriculture industry. By leveraging AI-driven drones, we are enabling farmers to achieve higher yields, reduce costs, and practice more sustainable farming methods. As we continue to innovate and expand our presence in the AI space, we remain committed to empowering farmers with the tools they need to succeed in an increasingly competitive and resource-constrained world. In conclusion, drones are being positioned as indispensable tools for addressing the agricultural challenges of the 21st century. Their capacity to provide precise data, optimize resource use, and improve productivity while contributing to environmental sustainability paves the way for a sustainable agricultural revolution. Realizing this potential will require close collaboration among researchers, industry professi-onals, policymakers, and farmers to overcome the identified challenges while ensuring ethical and responsible adoption of these technologies.

Guano Fertilizer: Nature's Potent Plant Booster

Britan Rahman and Mrinal Choudhury

Introduction

The word *guano* comes from the Quechua word '*wanu'*, meaning "dung." Indigenous people of the Andes have used guano for thousands of years to fertilize terraced mountain farms. Guano fertilizer, a natural substance derived from the accumulated excrement of seabirds, bats, and seals, has long been prized as one of the most powerful organic fertilizers available. Rich in plant essential nutrients and possessing remarkable soil-enhancing properties, guano has played a critical role in agriculture for centuries. From ancient Andean farmers to modern organic gardeners, this unique natural resource continues to hold value for its high nutrient content and environmental benefits. Guano is a highly effective fertilizer due to the high content of nitrogen, phosphate, and potassium, all key nutrients essential for plant growth. In the 19th-century seabird guano trade played a pivotal role in the development of modern input-intensive farming. The demand for guano spurred the human colonization of remote bird islands in many parts of the world. Unsustainable seabird guano mining processes can result in permanent habitat destruction and the loss of millions of seabirds. Bat guano is found in caves throughout the world. Many cave ecosystems are wholly dependent on bats to provide nutrients *via* their guano which supports bacteris, fungi, invertebrates and vertebrates. The loss of bats from a cave can result in the extinction of species that rely on their guano. Unsustainable harvesting of bat guano may cause bats to abandon their roost. Demand for guano rapidly declined after 1910 with the development of the Haber-Bosch process for extracting nitrogen from the atmosphere.

What is Guano?

Guano is the dried excrement of birds or bats, commonly harvested from caves or coastal islands where large colonies reside. The most famous guano sources come from seabirds in Peru and bats in countries such as Indonesia, Thailand, and parts of Africa. Over time, the droppings accumulate and compact, forming nutrient-dense deposits.

Nutritional Composition

Guano is primarily valued for its three key plant nutrients:

Nitrogen (N): Promotes leafy growth and is essential for photosynthesis.

Phosphorus (P): Stimulates root development and flowering.

Potassium (K): Strengthens plant cells and improves resistance to pest and diseases.

The exact N-P-K ratio varies depending on the source, but seabird guano is particularly high in nitrogen and phosphorus, while bat guano often has a more balanced nutrient profile.

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In addition to NPK, guano contains trace micro-nutrients, growth enzymes and beneficial micro-organisms.

Historical Significance: Guano played a pivotal role in global agriculture during the 19th century. The "Guano Age" saw nations like Britain and the United States import thousands of tons of seabird guano from Peru and Pacific islands to boost crop production. The demand was so intense that it sparked the Guano Islands Act of 1856 in the U.S., allowing citizens to claim unoccupied islands rich in guano. Archaeological evidence suggests that Andean people collected seabird guano from small islands and points off the desert coast of Peru for use as a soil amendment for well over 1500 years and perhaps as long as 5000 years. Spanish colonial documents suggest that the rulers of the Inca Empire greatly valued guano, restricted access to it, and punished any disturbance of the birds with death. The guanay cormorant is historically the most abundant and important producer of guano. Other important guano-producing bird species off the coast of Peru are the *Peruvian pelican* and the *Peruvian booby*. The earliest European records noting the use of guano as fertilizer date back to 1548. Although the first shipments of guano reached Spain as early as 1700, it did not become a popular product in Europe until the 19th century.

Benefits of Guano Fertilizer

High Nutrient Concentration: Guano is one of the most concentrated natural fertilizers, delivering immediate and long-term nutrients.

Soil Conditioning: It improves soil texture, aeration, and microbial activity.

Organic and Sustainable: As a natural product, guano is ideal for organic farming and gardening.

Fast-Acting: Especially in its water-soluble form, guano provides rapid nutrient availability to plants.

Pest and disease Resistance: Some users report enhanced plant resistance to pests and diseases due to guano's micronutrient content.

Application Methods

Guano can be applied in several forms:

Dry Powder: Mixed into soil or used as a top dressing.

Tea: Steeped in water to create a liquid fertilizer, ideal for foliar feeding or root drenching.

Pellets: Easy to apply and less dusty than powder forms.

The frequency and amount of application depend on the crop type, growth stage, and guano concentration. It's important to follow guidelines, as over-application can lead to nutrient burn.

Environmental Considerations

While guano is a renewable resource, its extraction must be managed sustainably. Overharvesting, especially from fragile island ecosystems, can disturb bird and bat populations and damage habitats. Responsible sourcing, such as through certified organic suppliers, ensures minimal ecological disruption.

Conclusion

Guano fertilizer remains a standout option for gardeners and farmers seeking a natural, potent, and environmentally friendly way to nourish their plants. Its rich nutrient content and versatility make it a valuable tool in organic and regenerative agriculture. However, like all natural resources, guano should be used responsibly to balance productivity with sustainability.

Murraya koenigii: Its Nutritional and Therapeutic Value

Priyanka Deka

Abstract

Murraya koenigii belongs to the family Rutaceae. *Murraya koenigii* or curry leaf, a native Indian plant known for its aromatic leaves. It has nutritional and therapeutic properties. Its leaves are a good source of dietary fiber, protein, fat, carbohydrate, carotene, calcium, and iron. It also contains volatile essential oils which has special advantage for the health of hair and skin. *Murraya koenigii* support various heath functions due to their nutritional content. Curry leaves are mostly used as a flavouring agent while preparing dishes. The plant's applications extend to cosmetic, food and nutraceuticals industries.

Introduction

Murraya koenigii, a variety of curry leaves in the family Rutaceae. The genus Murraya has 12-15 species and is distributed in Asia, Africa, Australia and New Caledonia. *Murraya koenigii*is native to tropical Asia spreading from the Indian sub continent to Sri Lanka extending to Myanmar, Indonesia, China, and Hainan. It is cultivated in south-east Asia, Australia, United States, Nigeria, Kenya, Tanzania, and Indian Ocean islands. *Murraya koenigii* is a spreading tree with a 15-40 cm diameter trunk. The main stem and branches (10-50 tree^{-1}) are covered with dark grey to brownish bark with longitudinal striations encasing white-coloured wood (Rao, 2016). Curry leaves are a popular leaf-spice used in very small quantities for their distinct aroma due to the presence of volatile oil and their ability to improve digestion. Curry leaf (*Murraya koenigii*) is an important leafy vegetable. Its leaves are widely used in Indian cookery for flavouring foodstuffs. The leaves have a slightly pungent, bitter and feebly acidic taste, and they retain their flavour and other qualities even after drying. Curry leaf is also used in many of the Indian ayurvedic and unaniprescriptions (Singh *et al*., 2014).

History of Curry Leaves

The use of curry leaves as a flavouring for vegetables is described in early Tamil literature dating back to the 1st to 4th centuries AD. Its use is also mentioned a few centuries later in Kannada literature. Curry leaves are still closely associated with South India where the word 'Curry' originates from the Tamil 'Kari' for spiced sauces.

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An alternative name for curry leaf throughout India is Kari-Pattha. Today curry leaves are cultivated in India, Sri Lanka, Southeast Asia, Australia, the Pacific Islands and in Africa as a food flavouring (Singh *et al*., 2014).

Plant Profile of Curry Leaves

Kingdom: Plantae

Sub kingdom: Tracheobionta

Super division: Spermatophyta

Division: Magnoliopsida

Subclass: Rosidae

Order: Sapindales

Family: Rutaceae

Genus: *Murraya J. Koenig* ex L.

Species: *Murraya koenigii* L. Spreng.

Benefits of *Murraya koenigii* (Nishan and Subramanian, 2015)

Curry leaves are a veritable rainbow of health benefits, full of minerals including carbs, fibre, calcium, phosphorus, iron, magnesium, zinc, several vitamins, and flavonoids. It is widely used to treat a variety of conditions, including skin, hair, and renal issues, diabetes, obesity, dyspepsia, and anaemia.

High on Fiber: Curry leaves are a great way to get fibre. It improves the regularity of our bowel movements and digestive wellness. Not only does it help with nausea and diarrhoea, but it also regulates the body's blood sugar.

Loaded with Proteins: Curry leaves contain a lot of proteins, which are thought to be the building blocks of life. It boosts our immune system and is necessary for the body's healthy growth and development.

Powerhouse of Calcium: It is well recognized that calcium helps to maintain healthy bones. Curry leaves are a great source of calcium, which helps to strengthen bones and teeth and prevent conditions like osteoporosis and osteomalacia.

Rich in Phosphorus: Phosphorus, one of the most vital elements in curry leaves, aids with kidney purification. It helps to maintain a regular heartbeat, reduce excruciating post-exercise muscular spasms, and fortify bones and teeth. Phosphorus is required for the biological growth and repair of tissues and cells.

Abundance of Essential Oils: Curry leaves supply a range of volatile essential oils, such as α-pinene, sabinene, β-pinene, and α-terpinene, in addition to minerals and vitamins. Especially advantageous for the skin, hair, and dental health are these essential oils' anti-inflammatory in nature, antibacterial, anti-diabetic, anti-dysenteric, carminative, and digestive qualities. Along with helping with digestion, it also works well against hyperglycaemia and elevated cholesterol.

Nutritional Value of Fresh and Dehydrated Curry Leaves

Nutrients	Value of fresh curry leaves (100 g)	Value of dehydrated curry leaves (100 g)
Protein	6 g	12 g
Fat	1 g	5.4 g
Carbohydrate	18.7 g	64.31 g
Calcium	830 mg	2040 mg
Iron	0.93 mg	12 mg
β-carotene	7560 µg	5292 µg

Health Benefits of Curry Leaves

- ✓ Helps lower cholesterol level.
- ✓ Boost Digestion.
- ✓ Support Liver Health.

- ✓ Promote Hair Growth.
- ✓ Improve Eye Health.
- ✓ Promote Weight loss.
- ✓ Help Reduce side effects of Treatments.
- ✓ Improve Blood Circulation.
- ✓ Helps in managing diabetes.

Industrial Uses: The leaves, flowers, fruits, and seeds yield strongly scented essential oils of varying compositions. More than 100 compounds have been identified in the essential oils of different countries. Monoterpenoid, sesquiterpenoid, and mono and sesquiterpenoid-rich chemotypes have been reported in the leaf essential oils offering opportunity to the food industry to select desirable chemotypes to satisfy consumer preferences. The leaves and their essential oil find application as flavoring and seasoning agents in ready-to-eat food dishes and processed vegetarian and nonvegetarian food products. The essential oil is employed in soap, cosmetics and aromatherapy industries. The essential oil and leaf products are effective in controlling stored grain, vegetable pests, and in extending shelf-life of meat and chicken patties. The essential oil exhibits antioxidant, antibacterial, antifungal, and insecticidal activities (Rao, 2016).

Conclusion

Murraya koenigii is a highly potential medicinal plant**.** Curry leaves offers numerous health benefits including improved digestion, blood sugar control etc. It serves as a valuable ingredient in both culinary and medicinal practices, from flavour enhancement to overall wellness support.

References

Rao, B. R. R. (2016). Curry Leaf (*Murraya koenigii*) Oils. Essential Oils in Food Preservation. *Flavour and Safety*, 43: 385-394.

Singh, S., Omreb, P. K. and Mohan, S. M. (2014). Curry Leaves (*Murraya koenigii* Linn. Sprengal)-A miracle plant. *Indian Journal of Scientific Research,* 4(1): 46-52.

Nishan, M. and Subramanian, P. (2015). *Murraya koenigii* (curry leave)-A review on its potential. *International Journal of Pharm Tech Research*, 7(4): 566-72.

https://www.medicoverhospitals.in/articles/benefits-of-curry-leaves

Biopolymer Producing Microorganisms

Alok Kumar Pandey, Smithavivek and Ramachandra Naik M.

Introduction

The worldwide population is consistently expanding, necessitating the expansion of the food supply and putting pressure on the limited available natural resources. This shift has ushered the agricultural sector into forming a noteworthy amount of waste. The environment is frequently being polluted due to rapid industrialization and the shift of populations to urban areas, leading to several concerns such as water pollution, waste expulsion in the surroundings, and environmental deprivation (Roa *et al*., 2021). Faced with this significant increase in the global population, modern agriculture is proving to be an advantageous solution since it offers the opportunity to upsurge crop yield. However, it also led to an increase in the global carbon footprint, and the generation of waste from farming impacts the economic and social sectors. According to FAO (2019), agriculture comprises around 38% of the terrestrial surface area on Earth. The Food and Agricultural Organization (FAO) stated that the amount of food wasted annually during farming, post-harvesting, and agriculture processing was 1.3 billion tons.

Given that landfilling agricultural leftovers contributes to global warming, using them and turning them into biopolymers offers a fantastic chance to lower the global carbon footprint. Growing awareness of various environmental issues has prompted the creation of fresh strategies to lessen their worsening impacts. Because it is superior to synthetic biopolymers in terms of sustainability, biodegradability, cost-effectiveness, structural variety, non-toxicity, and bioactivity, the production of microbial biopolymers has garnered significant attention among the many methodologies. This is due to a customized range of functional groups with defined molecular weights. Biodegradability relies on its chemical network so that it can be debased by biological attack. Moreover, the approach to the degradation of biopolymers relies on factors such as dampness, tempera ture, and pH. However, various functional, thermal, morphological, and rheological tests are usually executed to check its capability. Nowadays, many synthetic polymers are more admissible and have become a regular part of our lives, including dyes, Teflon, plastic polyester, etc. Biopolymers are described as a considerable group

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of molecules separated from their cell walls and based on repeated functional units at a specific level. Microbes are cell-forming manufactories that can transform carbon and nitrogen into extensive amounts of extracellular, intracellular, and capsular biopolymers. Based on chemical configurations, microbial biopolymers are classified into polyphos-phates, nucleotides, polysaccharides, polyamides and polyesters. Among all polyesters, biopolymers are widely adequate and are manufactured through metabolic pathways.

Biopolymer producing microorganisms

Bacteria: *Azotobacter* sp. is able to produce a biopolymer named poly hydroxy 3-butyrate i.e., PHB. This biopolymer is being utilized in preparation of grow bags and is also used as an alternative of plastic. *Escherichia coli* and *Bacillus cereus* are able to produce polyhydroxyalkanoates (PHA) that is being utilized in mulching and netting processes in agriculture. PHA also improves soil property and enhances plant growth. *Pseudomonas aeruginosa* is able to synthesize a biopolymer named alginate that is being utilized in formation of hydrogels, fibers, films and nanoparticles for various purposes, such as drug delivery, cell encapsulation etc.

Fungi: It is known that *Fusarium equiseti* produces a heteroglucan with antioxidant qualities that is composed of glucose and mannose subunits. Similarly, *Aspergillus terreus* produces a hetero-polysaccharide composed of galactose and mannose monomers that has anti-oxidative qualities.

A homoglucan-type polymer with pinocytic qualities is present in *Penicillium* sp., *Trametes versicolor* has yielded a heteroglucan polysaccharide with anti-cancer properties.

Actinomycete: *Streptomycesis* an actinomycete that is able to produce a biopolymer named dextran having various applications in food and pharmaceutical industries. Polyhydroxyalkanoates (PHA) produced by *Mycobacterium smegmatis* is a biopolymer having various applications in agricultural sector in improving soil property and plant growth. *Nocardia* sp. and *Corynebacterium* are producing polyhydroxybutyrate (PHB) being utilized in preparing grow bags as an alternative of plastic inpackaging and controlled release of drugs. *Rhodococcus* sp. is producing polypropylene and polyethylene biopolymers which are being utilized as bioplastics.

Various Biopolymer Synthesized by Micro-organism

Bacterial Cellulose: Waste, including agricultural residue, food waste, and industrial leftovers, can give bacteria the nutrients and habitat they need to create bacterial cellulose. Examples of raw materials used for obtaining bacterial cellulose are by-product streams from sugarcane jag gery waste waste streams from biodiesel and confectionery industries, oat hull, rice bark, corn stalk, fruit juices, Nylon 6-6 hydro-lysate, cotton-based textile waste, the wastewater of fermentation industries, etc (Skiba *et al*., 2020). Bacterial cellulose is chiefly isolated by both Gram-positive bacteria and Gram-negative bacteria such as

Komagataeibacter spp. *Acetobacter* spp., *Sarcina ventriculi*, *Pseudomonas* spp., etc. Zhong (2020) also concluded that due to the high cost of bacterial-cellulose production, its application is limited as compared to plant based cellulose. Consequently, novel affordable nutrient sources such as fermentation effluent, sugarcane molasses, and waste from fruits could additionally be utilized for the bacterial-cellulose upscaling manufacturing process. The manufacturing process of bacterial cellulose and its commercial usage has been constrained by high production costs as well as low yield. Bacterial cellulose-producing bacteria have no capacity to co-produce additional compounds with cellulose, such as lignin, pectin, and hemicellulose.

Xanthan Gum: Xanthan gum is an exopolysaccharide secreted by the commercially cultivated *Xanthomonas campestris* bacteria. It is a microbial biopolymer with a high molecular weight that falls under the heteropolysaccharide group. Glucose and sucrose from the substrate provide the majority of the carbon needed to produce xanthan gum. Glucuronic acid, mannose, and glucose units of repeat are connected by β (1-4) links to form xanthan gum. Usually, an aerobic fermentation process combined with isopropyl alcohol precipitation is used to obtain it.

Microbial β-Glucan: Cereals and non-cereals with different compositional structures are traditionally separated depending on raw materials used in β-glucan isolation. Furthermore, some microorganisms have the ability to produce exopolysaccharides, which might be used to meet industrial need. Micro-organisms' exopolysaccharides are beneficial substitutes for naturally occurring plant polysaccharides due to their unique metabolic properties. The properties of beta-glucan are influenced by its source. The procedure has certain limitations when it comes to industrial scale-ups of β-glucan, most notably long extraction periods and expensive expenses. Zhu *et al*. (2016) summed up the production of β-glucan using different processes and compared the yields and production times. The biological activity of obtained β-glucan depends upon raw material, manufacturing processes, and purifying techniques.

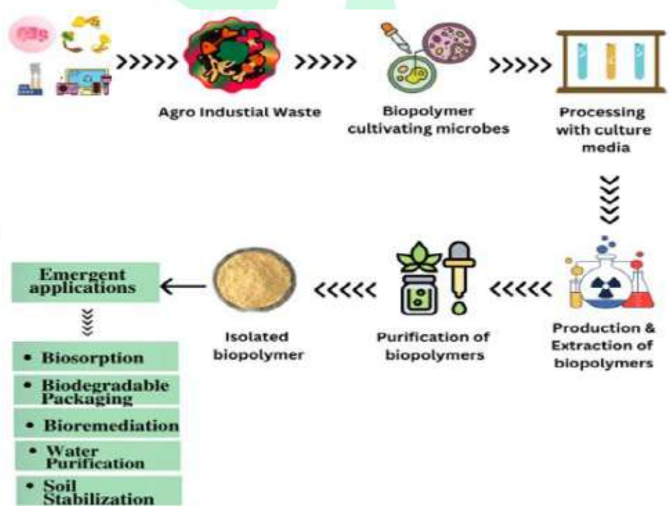
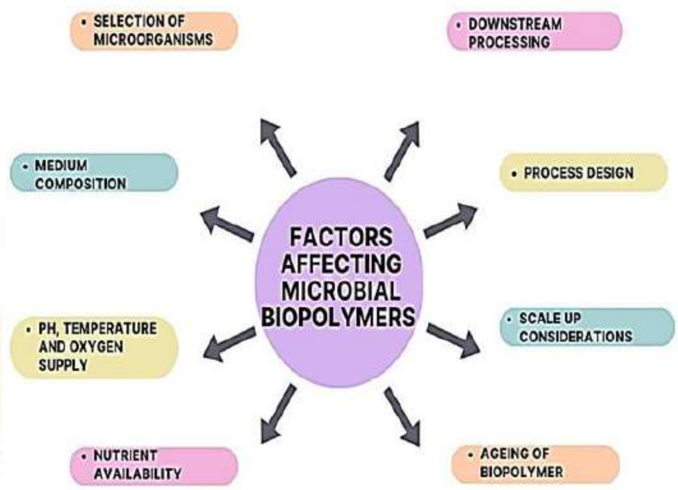


Table 1: Microbial Synthesized biopolymers and their applications

Type of biopolymer	Microorganism	Applications
Pullulan	*Aureobasdium pullulans*	Oil recovery
Cellulose	*Acetobacter xylinum*	Wound dressing
Cellulose	*Komagataeibacterrhaeticus*	Gluten-free bread formulation
Alginate	*Azotobacter vinelandii*	Wound dressings
Levan	*Tanticharoenia sakaeratensis*	Immunomodulatory effects
Xanthan	*Xanthomonas campestris*	Thickening agent
PHA	*Bacillus thermoamylovorans*	Biofuel production

Alginate: Alginate is majorly extracted from seaweed species, e.g., *Sargassum cristaefolium, Laminaria digitata,* and *Ascophyllum nodosum* and from some bacterial strains, e.g., *Pseudomonas* spp. and *Azotobacter* spp. Alginate is an unbranched water-soluble hy drocolloid that belongs to the polysaccharide category. Guluronic and mannuronic acid repeating monomeric units are adjoined by glycosidic connections to form alginate. The arrangement and composition of monomers designate the overall characteristics of alginate. Alginates could provide a cross-link (egg-box) structure through ionic interactions and trapping cations. This chelating structural arrangement provides alginate with the capability of quenching heavy metals from wastewater. Hydrogels can be formed from alginate with the addition of calcium ions, which are usually stimulated by the incorporation of acids such as acetic acid.

Pullulan: Pullulan is a fungal-based microbial biopolymer that belongs to the family of exopolysaccharides. It is extracted with fermentation approaches by utilizing the fungal strain *Aureobasidium pullulans*. Pullulan is comprised of replicating units of maltotriose adjoined jointly by α-(1,6) glycosidic joinings. Maltotriose is an oligosaccharide, which is further composed of three glucose units adjoined by (1,4) glycosidic joinings. Elevated fermentation-broth viscosity, melanin coloring, and pullulanolysis during fermentation are the main issues encountered during the manufacturing of pullulan. Pullulan exhibits applications in the bioremediation of industrial waste streams, biosorption of heavy metals, harmful dyes, antibiotics and other pollutants in water due to its robust adhesive at tributes (Rashid *et al*., 2023). The use of synthetic polymers for food packaging has increased over time due to their mechanical and thermal attributes, but the decomposition of these polymers leads to the production of harmful gases (Jafarzadeh *et al*., 2020).



Conclusion

Biopolymers represent one of the best ways to deal with increasing environmental pollution. Biopolymers hold the highest position due to their biodegradable and eco-friendly behavior. The unique properties of biopolymers also make them a suitable material for industrial purposes. Despite being advantageous in several ways, they have not gained a major market share. As a cost-effective source, microorganisms are being exploited for production of biopolymers. In recent years application of biopolymer producing microorganisms are at a high rate.

References

Roa, K., Oyarce, E., Boulett, A., A. L. Samman, M., Oyarzún, D., Pizarro, G. D. C. and Sánchez, J. (2021). Lignocellulose-based materials and their application in the removal of dyes from water: A review. *Sustainable Materials and Technologies*, 29: e00320.

FAO. (2019). Background Notes on Sustainable, Productive and Resilient Agro-Food Systems : Value Chains, Human Capital, and the 2030 Agenda; FAO: Rome, Italy, pp. 1-70.

Skiba, E. A., Budaeva, V. V., Ovchinnikova, E. V., Gladysheva, E. K., Kashcheyeva, E. I., Pavlov, I. N. and Sakovich, G. V. (2020). A technology for pilot production of bacterial cellulose from oat hulls. *Chemical Engineering Journal*, 383: 123128.

Zhong, C. (2020). Industrial-scale production and applications of bacterial cellulose. *Frontiers in Bioengineering and Biotechnology*, 8: 605374.

Jafarzadeh, S., Jafari, S. M., Salehabadi, A., Nafchi, A. M., Kumar, U. S. U. and Khalil, H. A. (2020). Biodegradable green packaging with antimicrobial functions based on the bioactive compounds from tropical plants and their by-products. *Trends in Food Science & Technology*, 100: 262-277.

Rashid, A., Qayum, A., Liang, Q., Kang, L., Raza, H., Chi, Z., ... and Ma, H. (2023). Preparation and characterization of ultrasound-assisted essential oil-loaded nanoemulsions stimulated pullulan-based bioactive film for strawberry fruit preservation. *Food Chemistry*, 422: 136254.

AI and Robotics in the Food Industry

Archana Bhagat, Munazza Aslam Khan and Gautam Gupta

Introduction

Food safety remains a global concern, as supported by its estimated global impact on the econ omy and public health. Most recent estimates by the World Health Organization (WHO) indicate that globally every year, foodborne illnesses cause 600 million cases, resulting in 420,000 deaths and the loss of 33 million disability-adjusted life years (WHO, 2015). Overall, progress in reducing food-borne illnesses globally has been slow and challeng-ing. For example, foodborne illness rates for key foodborne pathogens in the United States (e.g., *Salmonella, Listeria monocy togenes*) have been relatively steady over the past decade. Reducing foodborne infections presents a variety of intricate problems that vary greatly by nation, area, and the particular virus and foods in question. The prevalence of foodborne illness is virtually unknown in many nations, mostly because of a lack of public health surveillance systems and a methodical approach to foodborne pathogen surveillance. The price and complexity of effective foodborne disease surveillance also operate as a barrier, even while a focus on other public health issues that are thought to be more pressing and significant (such as HIV and malaria) may be one explanation for the lack of surveillance. Notably, the WHO officially acknowl-edged the impact of foodborne illness on public health. Artificial Intelligence (AI) is revolutionizing the food business by improving productivity, safety, and quality control. Traditional techniques of inspection and quality assurance are no longer enough in light of the increased demand for safe and high-quality food items worldwide. The way that food quality is evaluated and preserved is being completely transformed by AI-driven technologies, such as machine learning, computer vision, and predictive analytics. AI is essential to ensuring that food satisfies the highest safety and quality standards from identifying pollutants in food products to streamlining supply chains and cutting waste. Large volumes of data may be precisely analyzed by automated systems, which lowers human error and speeds up food inspections. Additionally, AI-powered sensors and imaging technologies can identify defects, adulteration, and spoilage at an early stage, preventing unsafe products from reaching consumers.

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Artificial intelligence (AI), as a far-reaching emerging technology, has experienced birth, ups, and downs, and the harvest, not only impacting our personal lives but also essentially transforming how firms make decisions (Haenlein *et al*., 2019). Machine learning (ML) is currently a main branch of AI, integrating probability theory, statistics, and convex optimization to resolve the problems of computer vision, speech recognition, natural language pro cessing, robot control, etc. (Jordan and Mitchell, 2015). The International Standards Organization (ISO) defines a robot as, "An automatically controlled, re-programmable, multi-purpose, manipulative machine with several degrees of freedom, which may be either fixed in place or mobile for use in industrial automation applications." Robots are especially desirable for certain work functions because, unlike humans, they never get tired; they can work in physical conditions that are uncomfortable or even dangerous; they can operate in airless conditions; they do not get bored by repetition; and they cannot be distracted from the task at hand.

Reasons for automating processes

- ✓ Need to reduce direct labor
- ✓ Can't get people to do the job
- ✓ Need to increase quality
- ✓ Difficult to do the job manually
- ✓ Need to increase production
- ✓ Difficult to meet specifications consistently
- ✓ Need to provide flexibility in processes
- ✓ Hazardous to personnel
- ✓ Eliminates a contamination source

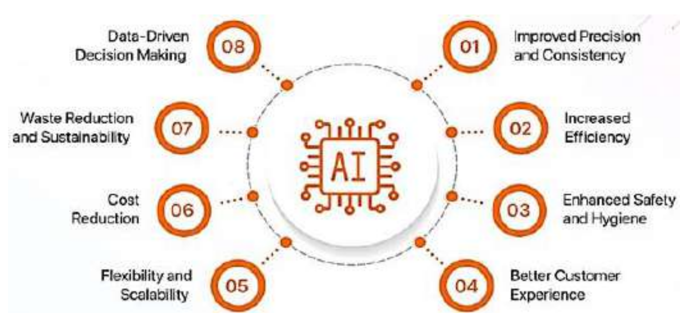
Application of AI & Robotics in Food Industry

Betterment of Food Handling: Robots can assist in creating the flavor profiles of customers, and new recipes can be developed using information gathered from customers over time. It enhances one's general well-being at work, particularly when engaging in physically taxing activities like repetitive fruit and vegetable chopping and heavy lifting. It may lessen skeletal and muscular issues, which are frequently connected to the food industry. AI-powered smart agriculture and the creative food sector. These techniques meet societal demands while simultaneously producing high-quality goods on schedule. Additionally, it facilitates the delivery, storage, and processing of food. Robotics and intelligent drones are examples of intelligent gadgets that can help reduce packing costs. Additionally, it facilitates the delivery of meals, the performance of tasks in hazardous areas, and the supply of high-quality goods (Grobbelaar *et al*., 2021).

AI Robotic in Fruit Industry: Robots can assist in creating the flavor profiles of customers, and over time, data collected from customers can be used to develop new recipes. A person's general well-being at work is enhanced by it, particularly when engaging in physically taxing activities like repetitive fruit and vegetable cutting and heavy lifting. Muscular skeletal issues, which are frequently connected to the food industry, may be lessened by it. The inventive food industry and AI-powered smart agriculture These techniques provide timely, high-quality products while simultaneously addressing societal needs. It also aids in the distribution, storage, and processing of food. Packaging costs can also be reduced with the help of intelligent gadgets like intelligent drones and robotics. It also aids in the delivery of food, the completion of tasks in dangerous situations, and the supply of high-quality goods. Machine vision technology can be used to rapidly and reliably identify any damaged or contaminated apples and remove them from a production line (Chen *et al*., 2022).

AI Robotic in Agriculture: The agri-food industry is becoming more digital as a result of the threats that cause widespread contamination. Digital innovations like AI, big data, and robotics have the potential to help businesses and farmers in a variety of ways. AI can be applied to precision agriculture, weather forecasting, irrigation optimization, and soil quality assessment, for instance. Big data can be used to trace supply chains, monitor agricultural growth, and offer insights for wiser decision-making (Micle *et al*., 2021).

AI Robotic in Food Logistic: To increase overall sustainability, food logistics must lower carbon emissions and logistics costs. Automation is the employment of other automatic mechanized technologies such as a robot to complete certain duties. Any corporation using robotics and automation does so because it wants to cut costs, boost production, and speed up operations. Robotic and automated processes also offer more efficiency and a better working environment. In order to guarantee end-to-end tracking and traceability in the food supply chain, robotics and automation can be extremely important. The rapid growth of intelligent control technology has influenced the logistics business, resulting in the deployment of novel concepts for autonomous indoor logistic robots. These robots move commodities and packages around warehouses and factories. A tremendous motivation exists to minimize the cost of these mobile robots and build flexible control methods. To achieve the flexibility and cost-effectiveness of the newly created mobile robot solution, new technology such as AI and machine vision are applied.



AI Robotics for Equipment Cleaning and Maintenance: Cleaning and maintaining processing equipment properly is crucial in the food processing industry. AI-based systems can readily manage such a task. Several sensors and cameras are used to carry out the task in order to do this. Whitwell and Market product suffers from the fact that it can only drop below 50%, allowing for high efficiency and less time. Market is currently attempting to defend its AI-based cleaning station concept. Market uses optical fluorescence and ultrasonic sensing imaging techniques for this approach in order to cultivate the information gathered for the development of the AI system.

Launching New Products: The launching of new products for any production unit is a tedious task. Especially, in the case of food industries, it totally depends on the consumer's interests. Therefore, the information collected by the various decision-making systems for customers is helpful for the launching of new products. The collected information is processed by the ML-based module and then takes the proper decision for the product (Misra *et al*., 2020).

Conclusion

AI robotic automation is widely used and versatile in a variety of food processing industries; it contributes to a safer workplace and less contamination from food handling. Employees that are able to use AI robotics will be able to increase their productivity and efficiency at work. Aside from that, this study offers insightful data and some implications for further research on AI robotics. The food industry is now using the most basic kind of artificial intelligence. AI's function is getting more and more important every day because of its capacity to improve waste management, food safety, and hygiene. AI has the ability to produce reasonable and healthier productivity for both customers and staff, which is why it will revolutionize the food processing business in the future.

References

Haenlein, M. and Kaplan, A. (2019). A brief history of artificial intelligence: On the past, present, and future of artificial intelligence. *California Management Review*, 61(4): 5-14.

Jordan, M. I. and Mitchell, T. M. (2015). Machine learning: Trends, perspectives and prospects. *Science*, 349(6245): 255-260.

WHO (World Health Organization). (2015). WHOEstimatesof the Global Burden of Foodborne Diseases. Geneva: WHO.

Grobbelaar, W., Verma, A. and Shukla, V. K. (2021). Analyzing human robotic interaction in the food industry. In *Journal of Physics: Conference Series* (Vol. 1714, No. 1, p. 012032). IOP Publishing.

Chen, T. C. and Yu, S. Y. (2021). The review of food safety inspection system based on artificial intelligence, image processing and robotic. *Food Science and Technology*, 42: e35421.

Micle, D. E., Deiac, F., Olar, A., Drența, R. F., Florean, C., Coman, I. G. and Arion, F. H. (2021). Research on innovative business plan. Smart cattle farming using artificial intelligent robotic process automation. *Agriculture*, 11(5): 430.

Uses of Bamboo Including Ethno-Botanical Importance

B. Bhavani and Ramachandra Naik M.

Introduction

Bamboo, well known as the poor man's timber or green gold, is one of the world's highest-yielding renewable natural resources. It belongs to the family Poaceae, a subfamily of Bambusoideae, and has 75-107 genera with over 1642 known species of bamboo worldwide (Vorontsova *et al.*, 2016). Bamboo is a widely distributed grass in the tropical, sub-tropical belts and mildly temperate regions between latitudes around 46° north and 47° south covering Asia, Africa, north, central and south America. The total estimated bamboo resource in the world is 35.0 million ha, of which 24.9 million ha (71% of the total bamboo area) is in Asia. Most of the Asian forests have bamboo, with its significant presence in Northeast (NE) India through Burma to southern China, and through Sumatra to Borneo. The total area under bamboo in the world increased by around 50% between 1990 and 2020, mostly because of the increases in China and India. India is a major bamboo-producing country covering 15 million ha (FSI, 2021) followed by China which covers 6.01 million ha. In terms of bamboo diversity, China is among the richest countries in the world and alone has about 861 species belonging to 43 genera. India has reported around 148 species of bamboo belonging to 33 genera and 6 different varieties. Around 70% of the overall bamboo forest area in China is dominated by moso bamboo (*Phyllostachys pubescens*), whereas in India the widely dis tributed bamboo genera are *Bambusa* and *Dendrocalamus*. Due to their biological attributes and rapid growth, bamboo forests are ecologically important for their role in carbon sequestration, soil erosion control, water conservation, and land rehabilitation. Bamboo acts as a potential carbon sink and can improve land and water quality, thus improving the microclimate. It also has enormous potential for the eco-restoration of degraded lands. In addition to the diverse eco-system services provided by bamboo grown in villages, total biomass and carbon storage in bamboo based family forests can provide an opportunity for carbon farming. Bamboos can provide local coping strategies that increase the resilience of ecosystems. Bamboo has different ethnobotanical applications in different places. It has played a crucial role in Indian culture, society and economy custom. They can be used for a wide range of purposes because of their strength, straightness, light weight, and exceptional hardness range of size, abundance, and fast maturity

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Table 1: Traditional bamboo products commonly manufactured by bamboo craftsmen

Items	Local name	Used for
Winnowing receptacle	Supe	Winnowing of food grains
Large basket	Gaanja	For keeping food grains
Big basket	Tokri	For keeping hen
Medium basket	Tokri	For filtering rice water from cooked rice
Medium basket with handle	Mouni	For keeping kitchen items
Small basket	Mouni	For collection of Mahua flower and keeping kitchen items as vegetables
Fencing mat	Chatai	Wall of rooms
Tree guard		Protection of seedlings from cattles
Hand fan	Pankha	Hand fan
Ladder	Lishan/ sidhi	For climbing
Fishing apparatus	Chiyari	For capturing fish
Small Basket-supe	Supli Mouni	Used during marriage rituals
Medium size basket	Khanchia	For collection of various crop in agriculture field
Strong basket	Douri	For grain storage
Piece of bamboo	Akhain	For mixing & stirring paddy
Balance	Taraju	For weighing crop and vegetables
Broom	Jhadu	For collection of animal dung
Big strong basket	Dala	For storage of grains and other crops
Small strong basket	Dalia	For storage of vegetables
Small stick	Chhadi	To handle the cattle during driving Bullock cart

period. Bamboo can be used for a wide range of purposes, including construction, scaffolding, handicrafts, agricultural equipment, weaponry, musical instruments, food, fuel, feed and numerous environmental issues.

Structure: The structure of bamboo, which determines its ultimate mechanical qualities, is described in the anatomy of bamboo. The above-ground stem, which may be straight or bent. The stem base, which is the lower portion of the stem that reaches the ground. The stem petiole, which is composed of several short sections and is the lowest part of the stem. The culm, which is the main stem of a plant, is made up of two key parts: internodes and nodes (also called diaphragms). Nodes are areas where cells are oriented either across or parallel to the stem, while internodes are made up of cells that run along the length of the stem.

Most culms are hollow, like tubes, and the thickness of the stem's wall defines the space between the inner and outer surfaces. However, some plant species may have solid stems instead of hollow ones. Because of its high content of potassium, bamboo helps to maintain normal blood pressure and is labeled as a heart-protective vegetable.

Ethanobotanical Importance of Bamboo

Bamboo have been used to cure a variety of diseases in folk medicine. Bamboo shoots have been regarded as a traditional Chinese medicinal material for more than 2000 years. In the traditional system of

Indian medicine, the silicious concretions found in the shoots are called 'banslochan' and in the Indo Persian and Tibetan system of medicine, it is called 'tabashir' or 'tawashir' and commonly called as 'bamboo manna' in English (Nirmala *et al*., 2001). Modern research has revealed that bamboo shoots have a number of health benefits, from cancer prevention and weight loss to lowering cholesterol level, improving appetite and digestion etc. For instance, the people of Subhartipuram in India prescribed the leaves of *B. vulgaris* for the treatment of rheumatism (Singh *et al*., 2020). Additionally, *B. vulgaris* is prescribed to cure malaria, heart problems and clean out dilation. Kani tribals consume the seeds of *B. arundinacea* as a paste to cure rheumatism. Its relatively high content of up to 4% cellulose increases the peristaltic movement of the intestines and helps digestion. It also prevents constipation and decreases body fat. Due to high content of dietary fibres and presence of phyto-sterols, bamboo shoots are known to lower cholesterol level. Shoots of *B. arundinacia* / *B. bamboos* contain choline, betain, nuclease, urease, cyanogens, glucosides and are used in the treatment of diarrhoea, thread worm and cough.

Sustainable utilization of bamboo in land restoration

The bamboo plantation is crucial in the process of land restoration, and it holds a key role in the economic development of the country. It also provides important additional benefits as a commodity (Abebe *et al*., 2021). Many plants and grass-like bamboos will be able to manage the degrade lands and stop runoff due to their intensive root systems. Bamboo has exceptional environmental and biophysical properties that make it potential and economical approach to addressing some of the complex challenges of land degradation, which we are currently facing, particularly in areas of severe degradation. Bamboo has properties that make it perfect for recovering degraded lands. It can grow in poor soils and on steep slopes where several other plant species cannot survive. Its large fibrous roots allow it to stabilize in loose soils and prevent soil erosion. Multiple studies have revealed that bamboo's subterranean rhizomes and fibrous roots may cover up to 100 km ha^{-1} of the bamboo stand, develop to a depth of 60 cm, and survive for 100 years. Bamboo can survive even after destroying above-ground biomass due to its good regeneration capacity of rhizomes. Bam boo is one of the fastest growing woody trees, capable of growing up to one metre in a single day, owing to its enormous root system. Therefore, it may re-vegetate and restore productivity to barren land in a short duration. As a result, a grow ing number of governments have started to recognize as well as expressly list bamboo as a high priority plant for restoration of the landscape. Ethiopia, Ghana, China, Kenya, India, Cameroon, Madagascar, Vietnam, and Philippines are just a few of the nations that have made bamboo a priority in their plans to achieve Sustainable Land Management.

Bamboo plantation in phytoremediation

In phytoremediation, plants are used to shift, stabilize, extract, and/or get rid of pollutants in the groundwater and soil. A low-cost method of cleaning up contaminated areas is phytoremediation, which uses plants with exceptional metal-accumulation capabilities. The strategy is more palatable to the local population and less detrimental to the environment. Certain bamboo species have the ability to absorb heavy metals and adapt to metallic environments. Heavy metals, which are mostly deposited in the cell wall, vacuole, and cytoplasm, may accumulate in considerable amounts in the tissues of its rhizome and culm. It has been demonstrated that certain bamboo species, including *Phyllostachys edulis* and *P. praecox*, can absorb and retain heavy metals in contaminated soils.

Various Craft Products of Bamboo

Conclusion

For a long time, bamboo has been "poor man's timber", so it became the choice of material for most low-cost or cost-effective housing. Bamboo grows quickly and is in high demand, but its sustainability is under threat. We need to closely evaluate how renewable it is to meet both traditional and modern needs. Bamboo can thrive in almost any climate and can be harvested in 3 to 5 years, making it more versatile than many other woody plants. Despite being used for thousands of years, bamboo has not been depleted. However, we must explore advanced methods to use bamboo more effectively to ensure its long-term sustainability.

References

Vorontsova, M. S., Clark, L. G., Dransfield, J., Govaerts, R. and Baker, W. J. (2016). World Checklist of Bamboos and Rattans. INBAR and the Board of Trustees of the Royal Botanic Gardens, Kew: Beijing, China.

FSI (2021). India State of Forest Report 2021. Forest Survey of India, Ministry of Environment, Forest and Climate Change, GoI, Dehradun.

Abebe, S., Minale, A. S. and Teketay, D. (2021). Socio-economic importance of the bamboo resources in the Lower Beles River Basin, north-western Ethiopia. *Environment, Development and Sustainability*, 1-20.

Chongtham, N. C., Bisht, M. S. and Sheena Haorongbam, S. H. (2011). Nutritional properties of bamboo shoots: potential and prospects for utilization as a health food.

Singh, R., Upadhyay, S. K., Rani, A., Kumar, P. and Kumar, A. (2020). Ethanobotanical study of Subhartipuram, Meerut, Uttar Pradesh, India. II. Diversity and pharmacological significance of shrubs and climbers. *International Journal of Pharmacy Research*, 12(2): 383.

The Economic Footprint of GST on Agricultural Activities

Gosavi Deepali Prafulla, Brajesh Kumar and Shrikant H. Ban

Introduction

Agriculture is one of the most critical sectors of the Indian economy. Growth and development of agriculture and allied sector directly affects well-being of people at large, rural prosperity and employment and forms an important resource base for a number of agro-based industries and agro-services. The agriculture sector in India has undergone significant structural changes in the form of decrease in share of GDP from 30 per cent in 1990-91 to 17.4 in 2015-16 (Annual Report, 2015-16 MoA & FW) indicating a shift from the traditional agrarian economy towards a service dominated one. However, this decrease in agriculture's contribution to GDP has not been accompanied by a matching reduction in the share of agriculture in employment. About 52 per cent of the total workforce is still employed by the farm sector which makes more than half of the Indian population dependent on agriculture for sustenance. Over 15% of the total GDP comes from the agriculture sector. Corporate industries, such as those that produce agricultural machinery, are linked to the agriculture sector. Transportation and harvesting. In terms of raw materials, the food industry is likewise entirely dependent on agriculture. Agricultural products were subject to VAT, CST, OCTROI, and bought tax during the conclusion of the system. The majority of taxes were subject to state jurisdiction, with varying rates in each state. The majority of these levies were superseded by GST upon its establishment. Additionally, the National Agriculture Market (NAM) was founded by the national government. GST stands for “Goods and Services Tax” and is proposed to be a comprehensive indirect tax levy on manufacture, sale and consumption of goods as well as services at the national level. GST is an idea on which all the indirect taxes (by central government, state government and custom duties) will be subsumed into a common single GST. The proposed GST is expected to streamline the indirect tax regime. It contains all indirect taxes levied on goods, including central and state-level taxes. Act as an improvement on the VAT system, a uniform GST is expected to create a seamless national market. GST seems to be more comprehensive, compliable, simple, harmonized and development oriented tax system. Main aim of GST is “one nation, one tax”. From the consumer point of view, the biggest advantage would be in terms of a reduction in the

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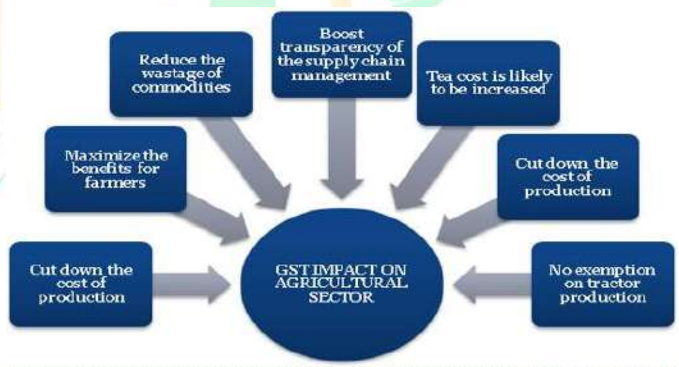
overall tax burden on goods, which is currently estimated to be around 25-30 per cent (Central Board of Excise and Custom). With the intention of simplifying the tax system and promoting a unified market across the country, India introduced the Goods and Services Tax (GST) on 1st July, 2017. There are a number of ways to assess how the GST will affect Indian farmers while accounting for the different aspects of their operations and sources of income. According to Shaik *et al*. (2015), GST benefits industry, trade, agriculture, and common consumers as well as the federal and state governments, ultimately contributing to the growth of the Indian economy. According to other reports, the GST will result in commercial gains that the VAT system did not address. Sehrawat and Dhanda (2015) studied, "GST in India: A Key Tax Reform" and concluded that due to dissident environment of India economy, it is demand of the hour to implement GST. It will give India a world class tax system by grabbing different treatment to manufacturing and service sector. The overall price level would go down. It is expected that the real returns to the factors of production would go up.

Key Features of GST

Single Indirect Tax: GST is a single, unified tax, meaning you don't have to pay a myriad of other taxes anymore, such as value-added tax, excise duty, service tax, and others. This unification has made tax compliance easier for businesses as well as reduced the cost of several goods and services. The GST rates vary depending on the nature of the goods or services and can range from 0% to 28%. Overall GST is helpful for the development of Indian economy as well it will be very much helpful in improving the gross domestic product of the country more than two percent mention by Chaurasia *et al*. (2016) in their study.

Registration exemptions for small businesses: All businesses must register under GST if their annual revenue exceeds Rs. 40 lakhs. The cap is Rs. 20 lakhs for Telangana and special category states. The GST threshold limits for service providers are Rs. 20 lakh for regular category states and Rs. 10 lakh for special category states. Small enterprises are exempt from registering under GST and collecting and paying taxes if they do not above the threshold restrictions.



Simplified Two-Tier GST Structure (5% & 18%) with 40% Sin Goods Rate

The GST tax structure in India has been

simplified as part of GST 2.0 reforms effective September 22, 2025. Previously, GST had four main slabs 5%, 12%, 18%, and 28% plus special rates and exemptions. Now, the GST Council has rationalized this into primarily two slabs:

- ✓ 5% for essential goods like daily essentials, agricultural products, and affordable healthcare items.
- ✓ 18% for most other goods and services, including electronics and small cars.
- ✓ In addition, a 40% demerit rate applies to sin and super-luxury goods such as tobacco, pan masala, and certain luxury vehicles.

Several essential goods and life-saving drugs have been exempted with a nil rate. This rationalization aims to make GST simpler, fairer, and more growth-oriented by reducing compliance complexity, cutting tax rates on essentials, and maintaining higher rates on sin goods to balance revenue needs.

Input Tax Credit System: It is the credit a registered GST taxpayer can claim for the GST paid on inputs (i.e., raw materials, capital goods, and services) that are used in producing or supplying goods and services. Under the GST system, the tax is levied at each stage of the supply chain, from the manufacturer to the retailer, and is ultimately borne by the final consumer.

Impact of GST on Farm Sector: The implementation of the Goods and Services Tax (GST) is anticipated to stimulate the agriculture industry because it would facilitate the easier transportation of agricultural goods due to improved product delivery. At every stage of the transaction, interstate trading of a specific product is frequently subject to separate taxes, permissions, and licenses required for multiple states. In the past, this has frequently made it difficult for many dealers to trade goods throughout the nation. Therefore, enacting GST would be the first step toward liberalizing agricultural product markets and facilitating seamless goods transactions. GST would make the agro-machineries affordable to the small and marginal farmers in India which was beyond their reach due to high excise duty on the machinery. Agricultural products were always subject to diversity in the taxation rates so a single rate of goods and service tax would benefit the national agricultural market and help the farmers and traders to sell their products in any part of the country and receive the best price for their product.

Influence of GST on Indian Agricultural Market

The Model GST law defines “agriculture” as floriculture, horticulture, sericulture, the raising of crops, grass, or garden produce, as well as grazing. However, it excludes dairy farming, poultry farming, stock breeding, the simple cutting of wood or grass, fruit gathering, the raising of man-made forests, and the rearing of seedlings or plants. As a result, the GST will apply to these. The experts claim that the primary effect of GST on agriculture would be inflation, with the present 4% VAT being raised to 8% on various food goods, such as grains and cereals, because the VAT exemption is only applicable to unprocessed food. The most affected from the inflation would be the consumers living below the poverty line. According to the survey conducted, approximately 60% of the respondents think that GST will have a positive impact on the Indian agricultural sector, however, 27% of the total respondents think the other way round (Kanwal *et al*., 2017).

Impact of GST on Supply Chain

- ✓ Transporters and Commission Agents now require GST registration
- ✓ Agricultural Produce Marketing Committees (APMCs) are partially affected in states with taxed services
- ✓ Cold chains and warehouses benefit from service exemptions but struggle with input cost taxation

Future Outlook

- ✓ Increased adoption of digital payments and invoicing will help small farmers formalize transactions.
- ✓ More rationalization of GST rates on essential agri inputs is expected.
- ✓ Possibility of bringing agriculture partially into the GST chain to allow input credit while maintaining exemptions for food security.
- ✓ Use of blockchain and AI to improve GST tracking and reduce fraud in agri-exports

Conclusion

Indian agriculture has experienced a mixed economic impact from the introduction of GST. Although primary produce and services are exempt, the industry faces both opportunities and difficulties as a result of input and value-added goods taxes. While agribusinesses have had to deal with growing expenses and compliance challenges, farmers do not receive input tax credits because they are primarily outside the GST chain. Though GST will face many challenges after its implementation, it will bring many benefits. Similarly, it will also be helpful in lowering the Tax burden on the various segments of the economy. Industries, dealers, retailers and the agriculture sector as a whole will benefit from GST. Agricultural sector is based on perishable items. And as forecasted in the Goods and Services Tax regime, if the supply chain evolves into something better, improving quick movement of goods, it will allow less food to be wasted. The profit in turn will go the farmers and the retailers.

References

Chaurasia, P., Singh, S. and Sen, P. K. (2016). Role of Goods and Service Tax in the growth of Indian economy. *International Journal of Science Technology and Management*, 5(2): 152-157.

Kanwal, V., Pandey, D., Rai, C. K. and Lal, P. (2017). Impact of GST on agriculture: A review. *Indian Journal of Economics and Development*, 13(2a): 65-68.

Sehrawat, M. and Dhanda, U. (2015). GST in India: A key tax reform. *International Journal of Research-Granthaalayah*, 3(12): 133-141.

Shaik, S., Sameera, S. A. and Firoz, M. S. C. (2015). Does goods and services tax (GST) leads to Indian economic development. *IOSR Jurnal of Business and Management*, 17(12): 1-5.

Role of Entomology in Ecosystem Harmony

Surekha Kamlesh Kurankar, Ramachandra Naik M. and Viresh Sadashiv Jeur

Introduction

Exploring the annals of history reveals a profound and complex relationship between humans and insects, characterized by fascination, wonder, and at times, fear. The historical perspective on insects not only traces the development of scientific understanding but also reflects humanity's evolving relationship with the natural world. It was during the Renaissance, with its emphasis on inquiry and the advent of the microscope, that the study of insects 'entomology' began to take shape as a formal scientific discipline. Pioneering entomologists such as Jan Swammerdam in the 17^{th} century conducted detailed anatomical studies of insects. Swammer-dam's meticulous dissections and documentation, particularly of insect life stages, challenged the long standing belief in spontaneous generation, demonstrating that insects undergo metamorphosis. This discovery was significant, as it not only deepened the understanding of insect biology but also influenced the broader development of biological sciences. Carl Linnaeus was another important player in early entomology. In the 18^{th} century, he introduced binomial nomenclature, which offered an organized method for categorizing the diversity of life, including insects. Despite several drawbacks, Linnaeus's classification scheme had a crucial role in structuring insect research, allowing for more methodical investigation and promoting the sharing of scientific insights. A delicate equilibrium in nature exemplifies the complexity and variety of life on Earth. Ecosystems exemplify the complex dynamics between interdependent systems, synergies, and relationships (Verma *et al.*, 2023). These are defined as interdependent structures composed of living and nonliving components. Whether terrestrial, aquatic, tropical, or temperate, these systems have undergone evolutionary changes spanning millions of years. A multitude of factors have influenced their stability and productivity. The predominant and most signi-ficant organisms that contribute to this equilibrium are insects. Insects are vital to maintaining ecological complexity, resilience, and overall health due to their extraordinary diversity and nearly global distrib-ution. Biologic and abiotic processes, such as energy transfer, herbivory, predation, and nutrient cycling, work together to support ecosystems (Saunders,

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2018). All organisms have a role in the food chain, regardless of their size or importance. The predator hunts its food, the butterfly pollinates flowers, and the earthworm aerates the soil to preserve ecological balance. Disturbances to this equilibrium, such deforestation, can have a cascading effect that is evident at several trophic levels, regardless of whether they are the result of human or natural causes. Explore the immense realm of insects, which symbolise the apex of biodiversity. To comprehend-sively understand their diversity, consider that insects comprise an estimated 10 million species, or more than 90 percent, of all known life on Earth. They are present everywhere, from the dense rainforests of the Amazon to the icy tundras of the Arctic (Sharma *et al*., 2023). The remarkable ability of insects to confound and motivate scientists and naturalists is evident in their capacity to inhabit virtually any ecological niche.

Insects as Pollinators: Because they are pollinators, insects play a crucial role in agriculture and ecosystems, with broad ramifications for both biodiversity and economic output. Knowing which insects are most active in this capacity is simply one aspect of comprehending the significance of insect pollinators; another is realizing their enormous economic worth and influence on ecosystem functioning. Despite its seemingly insignificant nature, pollination is an essential step in plants' sexual reproduction. Pollinators facilitate fertiliz-ation and seed formation by moving pollen from male anthers to female stigma.

Bees, both honeybees and solitary varieties, are perhaps the most well-known pollinators, but other insects like butterflies, moths, and even certain species of beetles and flies, contribute to this crucial process. Bees are typically the first insects to come to mind when discussing pollinators. The European honeybee, for instance, has been widely used in commercial pollination, especially in the United States and Europe. In natural ecosystems, bees pollinate a wide variety of plants, thereby maintaining plant diversity and the health of the ecosystem at large (Senapathi *et al*., 2015). Other bees like the bumblebee and various solitary bees also contribute to pollination. These bees are often more efficient than honeybees for certain types of flowers and under specific environmental conditions.

Insects in Soil Aeration and Decomposition

The contribution that insects provide to soil health is among their most underappreciated functions. As natural aerators, ants, beetles, and other soil-dwelling insects improve soil structure by form-

Table 1 : Significance of Insects in Ecosystems

Aspects	Description	Example
Role in Food Chains	Insects serve as primary consumers and are prey for higher-level consumers.	Caterpillars feeding on leaves; birds feeding on insects.
Soil Aeration and Decomposition	Certain insects contribute to soil health by aerating and breaking down organic matter.	Earthworms, ants, and beetles improving soil structure.
Pollination	Insects contribute to the pollination of plants, aiding in their reproduction.	Honeybees pollinating flowers.
Environmental Indicators	Insects can act as bioindicators, signaling the health of an ecosystem.	The presence or absence of certain insect species indicating water quality or pollution levels.
Adaptation and Evolution	Insects show high adaptability, providing insight into evolutionary biology.	The evolution of resistance to pesticides in mosquitoes.
Economic Impact	Insects have significant economic roles, particularly in agriculture.	Silkworms in silk production; bees in honey production.
Methodologies for Study	Both traditional and modern methods are used for studying insects.	Classical: Net trapping. Modern: DNA barcoding.
Conservation Implications	Understanding the role of insects in ecosystems is vital for conservation efforts.	Strategies to protect pollinators like bees and butterflies.
Future Research	Upcoming technologies and methodologies promise to advance the field.	Use of AI for species identification; eDNA for population monitoring.

ing channels that let nutrients, water, and air move deeper into the soil. The growth of plant roots and the general fertility of the soil depend on this type of aeration. Ants are diligent diggers, for instance. Their underground colonies are made up of a complex network of chambers and tunnels that serve as channels for gasses and water, boosting the porosity of the soil. Additionally, beetles especially ground beetles helps to aerate the soil. Various insects, including certain ants and beetles, are decomposers that help break down organic matter like dead plants and animals. By doing so, they accelerate the process of converting this organic matter into essential nutrients. These nutrients then become readily available for plants, effectively closing the nutrient loop (Ayilara *et al.*, 2020).

Insects as Bioindicators

The presence, abundance, or absence of certain insect species can serve as an effective tool for monitoring ecosystem health. Mayflies, caddisflies, and stoneflies, for example, are highly sensitive to water pollution and are often used to assess water quality. The decline in bee populations has been flagged as a warning sign of broader environmental degradation, given their crucial role in pollination. The monarch butterfly, whose migratory patterns are well-studied, serves as another bioindicator, with changes in its migration often reflecting habitat loss and climate change impacts.

Insects as Ecosystem engineers

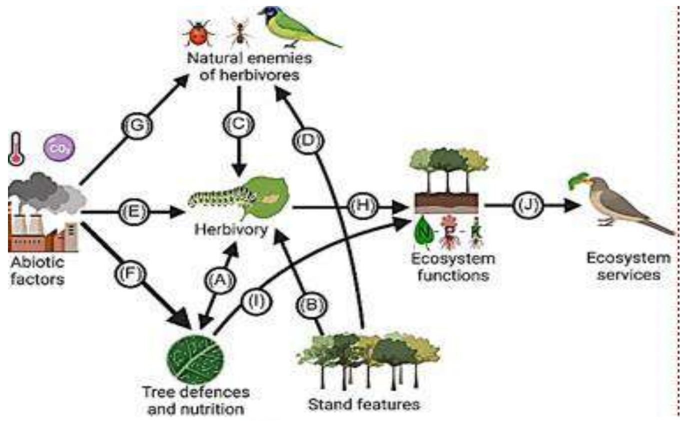
Ecosystem engineers are organisms that significantly alter their surroundings, either by developing new habitats or changing existing ones to better suit their requirements. By creating and preserving microhabitats that would not otherwise exist, ecosystem engineers have a substantial impact on other species. Ecosystem engineers are very frequently, though not always, referred to as keystone species because of the important roles they play in their surroundings and the broader effects they have on other species within the ecosystem. Without a keystone species, ecosystem function and biodiversity would be drastically diminished. Ecosystem engineers are those organisms capable to modify physically the environment in which they live.

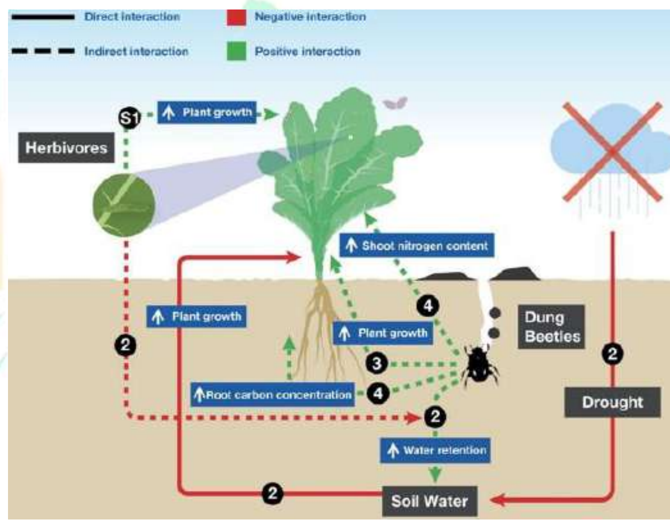
Insects as Edible Food

There is growing interest in insects as human food in academia, food and agricultural industries, public institutions and the public at large. As the public's awareness of nutritional security has grown, insects have been and will continue to be employed as a source of nutrient-dense food. Due to their high rate of reproduction, high rate of energy conversion, high capacity for survival, short life span, and small spatial requirements, insects will offer one of the more feasible options for ensuring food security. Insects can be reared and multiplied easily in small spaces and a short period due to their short life cycle and high intrinsic growth rate. The raising of edible insects is more environmentally beneficial than raising traditional livestock because they don't need to be fed grains (Oonincx *et al*., 2010).

Conclusion

Technological developments and the rise of new study areas are driving a revolutionary moment in entomology. For ecosystems to function and remain stable, insects are essential. Through pollination, decomposition, and pest control, they support ecological complexity, resilience, and general health. Pollination, which is necessary for the production of food crops, is the process by which insects reproduce plants. Additionally, they are essential for decomposition, which breaks down organic matter and replenishes the soil with nutrients. Predatory insects also lessen the demand for chemical pesticides in agriculture by controlling dangerous pests.





References

Ayilara, M. S., Olanrewaju, O. S., Babalola, O. O. and Odeyemi, O. (2020). Waste management through composting: Challenges and potentials. *Sustainability*, 12(11): 4456.

Oonincx, D. G., Van Itterbeeck, J., Heetkamp, M. J., Van Den Brand, H., Van Loon, J. J. and Van Huis, A. (2010). An exploration on greenhouse gas and ammonia production by insect species suitable for animal or human consumption. *PloS one*, *5*(12): e14445.

Saunders, M. (2018). Ecosystem services in agriculture: understanding the multifunctional role of invertebrates. In *Agricultural and Forest Entomology* (Vol. 20, p. 298). Wiley-Blackwell Publishing Ltd.

Senapathi, D., Biesmeijer, J. C., Breeze, T. D., Kleijn, D., Potts, S. G. and Carvalheiro, L. G. (2015). Pollinator conservation the difference between managing for pollination services and preserving pollinator diversity. *Current Opinion in Insect Science*, 12: 93-101.

Sharma, R. P., Boruah, A., Khan, A., Thilagam, P., Sivakumar, S., Dhapola, P. and Singh, B. V. (2023). Exploring the significance of insects in ecosystems: A comprehensive examination of entomological studies. International *Journal of Environment and Climate Change*, 13(11): 1243-1252.

Verma, R. C., Waseem, M. A., Sharma, N., Bharathi, K., Singh, S., Anto Rashwin, A., ... and Singh, B. V. (2023). The role of insects in ecosystems, an in-depth review of entomological research. *International Journal of Environment and Climate Change*, 13(10): 4340-4348.

Sound Production in Insects

Surekha Kamlesh Kurankar, Pottimurthy Venkatesh and Chandrashekhar R. Kasar

Introduction

Not only in most vertebrates, but also in many invertebrates, sound is of paramount importance for communication, for orientation and for recognition of potential dangers. Most of those invertebrates that can hear are insects. Hearing in insects has evolved independently several times and has led to an enormous biodiversity of auditory systems. From head to abdomen, from legs to wings, there is almost no part of the insect body which does not bear an ear in at least one group. This is astonishing if one considers how appendages such as legs and wings move and vibrate during locomotion. "Any mechanical disturbance which is potentially referable by the insect to an external and localized source" is what Haskell (1961) characterized as "insect sounds." Insects use sound-producing systems to find possible mates. Insects have developed communication systems and behavioral tactics, mostly chemical, optical, or auditory, to guarantee successful mating (Capinera, 2008). Intraspecific acoustic communication is facilitated by the particular hearing organs and sound generation mechanisms seen in many groups (Claridge, 2005).

Ewing (1989) described a most recognized classification compiling five categories of sound producing mechanisms. These are vibration, percuss-ion, stridulation, click mechan-isms, air expulsion. Sound emissions that result from vibrations of relatively unspecialized body parts of the insect are generally oscillations of the abdomen, either dorso-ventrally or laterally. The oscillatory movement of the wings of an insect sets up regions of compression and rarefaction and a vibrational sound is produced. Tremulation sound is transmitted through the legs to the substrate on which the insect is walking or standing. Percussion is striking one part of the body against another as a communication system for pair formation, as known for example, in the Australian moth (Lepidoptera). Stridulation consists of sounds produced by frictional mechanisms, involving the movements of two specialized body parts against each other in a systematic patterned manner. Air explosion sounds depend on the deformation of a modified area of cuticle, generally by contraction and relaxation of specialized musculature within the insect body. Hearing has evolved in several different behavioural contexts. Firstly, hearing may have evolved as an adaptation for detecting the approach

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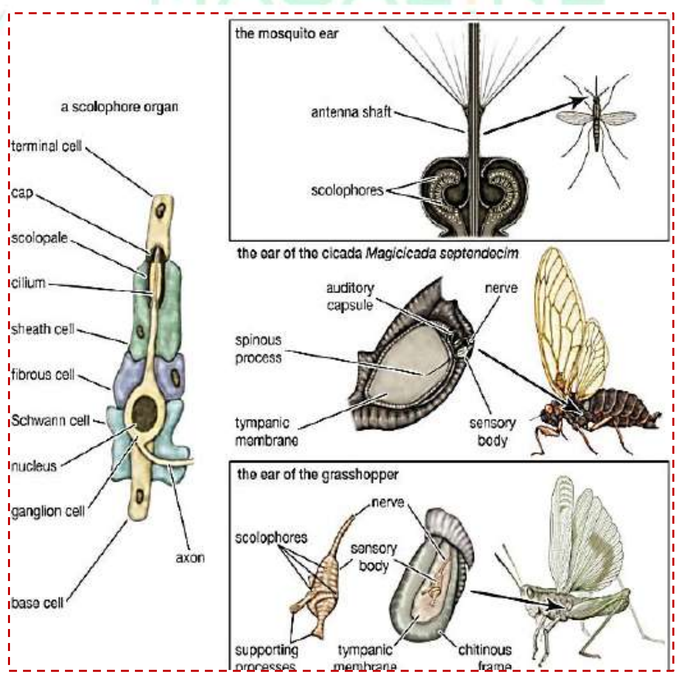
of predators, as is most likely the case in grasshoppers, mantises, moths, lace wings and beetles. Secondly, hearing and signaling may also have evolved in a coevolutionary process for mate finding and mate recognition, as has been suggested for crickets, bush-crickets, cicadas, and possibly water bugs. For the Ensifera and cicadas it is likely that acoustic signaling and hearing developed from vibratory communication may be in combination with enhancing pheromone signals-and this may be true for other taxa as well.

Functional Aspects of Sound in Different Contexts

The initial selection pressure for the evolution of hearing has probably strongly influenced the design and capabilities of the respective organ. Thus, investigating the initial functions may help us to better understand recent constraints or differences between groups. In this section, we will first focus on the detection of predators and then on intraspecific communication and host detection by parasitoids, since these tasks place different demands on the hearing organs. The following section will cover the relevance of carrier frequencies, which are of para mount importance for directionality of hearing systems and for signal transmission in the habitat, and communication distances.

Detection of Predators: Short latency escape maneuvers and early recognition of an approaching predator are extremely adaptive. As a result, in the context of startle and escape behavior, all accessible sensory modalities acoustic, vibratory and optical are typically exploited either alone or in combination. For instance, grasshoppers developed their ears at least 200 million years ago, most likely to hear the sounds made by predators like lizards and other terrestrial reptiles as they approached possible food. These motions can generate a wide variety of frequencies, including ultrasonic, depending on the substrate. A great impetus for developing ears in the context of predator avoidance arose some 60 million years ago when bats invaded the night niche of aerial hunters using ultrasound clicks to detect their prey by echo-location. In response, tympanal ears evolved in several taxa of nocturnal flying insects (several times independently in Lepidoptera, lacewings, beetles, mantises). In groups that already possessed ears, such as crickets and bush crickets (Rust *et al*., 1999), the hearing range was most probably widened to effectively perceive the ultrasonic clicks of bats.



Intraspecific communication: While hearing systems which evolved in the context of predator avoidance are optimized with respect to high sensitivity and short latency, the major selection pressures for those evolving in the context of communication were song recognition and sound localization (as the necessary prerequisites for successful mate finding), or song recognition alone in the case of male spacing, chorusing etc. These tasks require a more sophisticated neuronal network and complex signal processing, compared with the short latency escape responses involving only few synapses (see above). Signal recognition involves a neuronal filter mechanism that responds only to a limited range of the crucial signal parameters. Both subsystems, the sender signal and the receiver recognition mechanism, become matched in a process of coevolution with different and partly independent pressures on both sub systems. Signal evolution is mainly driven by the proper ties of the receiver recognition mechanism which, in turn, is selected to minimize confusion of "wrong" signals with the correct ones.

Song recognition: The parameters used for recognition may be the amplitude modulation of the signal or its spectral composition. In insects, recognition of a conspecific signal is mainly based on temporal pattern, i.e. the amplitude modulation, while the spectrum of the signals normally only plays a minor role. This is reflected in the enormous diversity of species-specific and stereotype song patterns found in acoustically communicating insects, whereas the spectra, especially of related species, usually differ much less from each other, as the sound producing systems are usually very similar.

Song localization: A relevant signal of a conspecific has not only to be recognized but also has to be localized. The cues for localisation are the interaural differences in ear drum vibration (which may be caused by interaural differences in pressure amplitude and/or phase) which are provided by the directional characteristics of the auditory system. A general mechanism to improve localisation is contralateral inhibition, which is a widely observed phenomenon among auditory neurons. However, strong contralateral inhibition at the first level of auditory processing may counteract the precise detection of temporal patterns. Therefore, it is not surprising that most auditory systems host both types of neurones, those that sum inputs and those that extract directional information: both over a large range of intensities. Relatively little is known about how the neuronal processes responsible for recognition and localisation inter act in the nervous system. Most of the information available comes from the Orthoptera, exemplifying two different ways of information processing. In grasshoppers recognition and localisation are processed in parallel; for pattern recognition the inputs from both ears are pooled, while for localisation the more strongly excited side de termines the response.

Temporal integration: An important aspect in the context of song recognition and localisation is the time over which a nervous system integrates in order to arrive at a decision. Song patterns are often highly repetitive and a minimum duration is necessary to recognize a signal (Padimi *et al*., 2023). This minimum duration may be well below 200 ms and may involve only one presentation of the elementary pattern unit. This is shorter than one might intuitively expect, considering that spike pat terns of neurones usually change considerably during the first several hundred milliseconds due to adaptation or habit-uation.

Detection of host signals: Some species of parasitoid flies use the acoustic signals of their hosts to detect them. Such a parasitoid/host system is similar to con specific communication in that a host must be both recognized and localized. However, in contrast to intraspecific communication, song pattern recognition in parasitoids may be less specific and include the song patterns of several (host) species. Among other parameters, the duty cycle of the host signal may be especially important and, where a choice is available, species with more repetitive songs are more likely to be infested.

Sound production mechanism in some common insects

Grasshopper: Among the grasshopper the sound is mainly produced by the process of stridulation during this process the sounds are often produced by a row of pegs on the inner side of each hind femur being worked against the outer surface of each tegmen.

Cricket: Sound in crickets produce may be use for their mating call or for defense purpose this sound generally produce in their wings on the underside of their wings there is tiny line or microscopic vein which is called FILE their wings also have sharp hard edges which are called Scapers due to their body movement the scapers inside the wings vibrate and due to this vibration the sound is produce. Same phenomenon occur in the house cricket, mole cricket and field crickets.

Cockroaches: Cockroaches also produce sound by the stridulating during this process they can rubbed the segments of the back of their neck region known as pronotum cockroaches can HISS loudly when they provoked by quickly whistling air out of their abdominal spiracles by rapid contraction.

Butterfly: brush footed and swallowtail butterflies have modified twerking an abdominal wiggling movement that triggers sound from tiny structures located at the membranes between their abdominal segments the twittering arises from a pair of so-called sound plates within each structure each of the two sound plates is covered with bumps and dips so that every bump on plat fits an associated dip on the other and interlocking surfaces that produces the sound.

Moth: Not all moth are capable of producing sound but some produce a squeaky noises are also known in some death’s head hawk moths they have cross-bones pattern on their heads make puzzle sound and second it sucks in air causing a flap between the mouth and throat called the epipharynx to rapidly vibrate the air is then expelled with the flap open creating a sound.

Locust: Almost the orthopteran can make sound by the process of Stridulation but there is little difference between grasshoppers and locusts generally the locusts can make sound by their wings when they fly the locust's wing membranes between the wing veins become stretched and rigid this stretching and relaxing of wing membranes produce sound.

Praying mantis: The process of sound production in praying mantis is very simple praying mantis can make a hissing sound when they are in danger this sound generally comes from when air passes through the spiracles present on the abdomen and in some species of mantis the loud hissing sound comes by shaking or rubbing their wings.

Conclusion

There are now seven orders of insects that have evolved tympanal organs for hearing in the distant field. Insect hearing most likely began as a way to identify and evade predators. Only five orders of insects are known to use sound signaling, which is much unusual and often takes place during mating communication. According to phylogenetic analyses, auditory communication originated through a "sensory bias" mechanism in the Lepidoptera and the suborder Caelifera (grasshoppers) of the Orthoptera. Hearing was inherited, and men later developed sound signaling on several separate occasions.

References

Capinera, J. L. (Ed.). (2008). Encyclopedia of Entomology. Springer Science & Business Media.

Claridge, C. (2005). Questions in early modern English pamphlets. *Journal of Historical Pragmatics*, 6(1): 133-168.

Rust, J., Stumpner, A. and Gottwald, J. (1999). Singing and hearing in a Tertiary bushcricket. *Nature*, 399: 650.

Padimi, V., Manisha, B. L., Singh, S. K. and Mishra, V. K. (2023). Communication in Insects: A Review. *Journal of Experimental Zoology India*, 26(2).

Plants as Source of Vitamin-D

Krishnagowdu Saravanan, Kamthenlal Dimngel, Sanskriti Verma and Srishti Sharma

Introduction

The main function of vitamin D is in maintenance and regulation of calcium levels in the body and vitamin D is, therefore, critically important for the development of a healthy skeleton. Thus, vita min D in sufficiency increases the risk of osteoporosis, but has also been linked to an increased risk of hypertension, autoimmune diseases, diabetes, and cancer (Kendrick *et al*., 2009). As a result, there is a growing awareness about vitamin D as a requirement for optimal health. Vitamin D_3 is synth-esized in the skin by a photochemical conversion of pro-vitamin D_3, but the necessary UVB rays (290-315 nm) are only emitted all year round in places that lie below a 35˚ latitude. Thereby, a dietary intake of vitamin D becomes essential, but very few food sources naturally contain vitamin D. The consequ-ence of a low dietary intake and limited vitamin D derived from the sun is that the general populations fail to meet their vitamin D requirements (Bailey *et al*., 2010). Fish have the highest natural amount of vitamin D_3, which is expected to derive from a high content of vitamin D_3 in planktonic microalgae at the base of the food chain. The occurrence of vitamin D_3 in algae suggests that vitamin D_3 may exist in the plant kingdom and vitamin D_3 has also been identified in several plant species as a surprise to many. The term vitamin D also includes vitamin D_2 that is produced in fungi and yeast by UVB exposure of pro-vitamin D_2 and small amounts can be found in plants contaminated with fungi. Traditionally, only vitamin D_2 has been considered present in plants. Although the skin produces vitamin D, dietary vitamin D intake is typically also necessary for good health. Nevertheless, there aren't many foods that contain vitamin D. The general population is unable to achieve their vitamin D requirements for health as a result of inadequate dietary consumption and restricted vitamin D from the sun. Vitamin D deficiency is an issue in areas with little sun exposure, and vitamin D supplementation is crucial for these populations. However, because there aren't many natural foods that contain vitamin D, dietary recommendations are challenging. Vitamin-D is also naturally found in eggs, pork, and some mushrooms but only at a small fraction of the recommended daily

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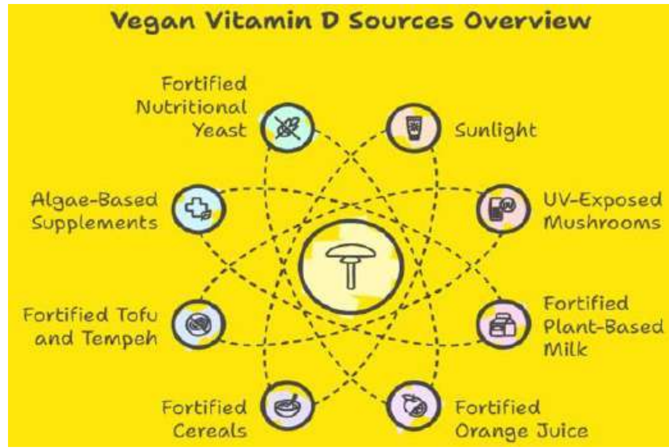
dose. As a result, the consumption of supplements of vitamin-D has increased exponentially in the last few decades, which has lead to an exploitation of the existing sources. Therefore, certain investigations that documented the detection of vitamin D or any vitamin D metabolite in plants are covered in this review. These discoveries ushered in a new phase of plant research aimed at identifying components similar to vitamin D for potential multi-factorial applications.

Dietary Intake and Recommended Daily Intake of Vitamin D

Because the body produces vitamin D_3, vitamin D does not meet the classical definition of a vitamin. Generally, fish have the highest natural amount of vitamin D_3, *e.g.*, salmon contains 30 µg/ 100 g and tuna 2.9 µg/100 g. The content of vitamin D in food of animal origin depends on what the animal has been fed (Jakobsen *et al*., 2007). The main compound in food is vitamin D_3, but the metabolites, which are part of the metabolic pathway in vertebrates also exist. Food sources of vitamin D_2 are very limited and wild mushrooms are one of the only significant sources of vitamin D_2. However, milk from dairy cows contains a significant although low amount of vitamin D_2, which is expected to derive from grass and hay. Vitamin D fortification of selected foods has been accepted as a strategy to improve the vitamin D status of the general population both in the United States and in many European countries. Milk and margarine are the primary products that are enriched with vitamin D, but also orange, juice, bread, cheese and yoghurt may be enriched (Holick, 2011).



Discovery of Vitamin D: Vitamin D has a long and fascinating history that goes back more than 350 years. It started with the discovery of rickets and osteomalacia by two research groups from the Netherlands and England during the early 1600s. By the late 1700s, Percival advocated the effectiveness of cod liver oil compared to gum guaiacum in the treatment of rickets suggesting a nutritional deficiency to be the causative factor of the disease which was later on identified as the vitamin-D. But on the other hand researchers like Sniadecki recorded a difference in incidence rates of rickets in rural and city children of Poland, hinting towards an environmental factor to be the major cause of ricket, which again led to the discovery of role of sunlight in rickets and osteomalacia. The dilemma about how both light and a dietary substance cured rickets was eventually resolved by the work of Chick *et al*. (1922) and Steenbock and Black (1925) who independently investigated the dual role of nutrition and sunlight exposure in the prevention of rickets. Steenbock was the first person who reported that an inactive non-saponiiable lipid fraction in the diet and skin could be converted by UV light into an active anti rachitic substance. At this point the exact chemical nature of vitamin D was still unknown to the world. It was in 1932 when for the first time Askew isolated vitamin-D_2 from an irradiation mixture of ergosterol and hence it became the first isolated form of vitamin-D. Again the structure of 7-dehydrocholesterol, and vitamin D_3 was first time elucidated by Adolf Windaus, who got 1928 Nobel Prize for this discovery. Thereafter further research suggested that vitamin-D_3 is only present in animal food and plants contain a precursor of ergocalciferol (Vit-D_2/ ergosterol), that converts into vitamin-D_3 to be utilized by the human body. However around 2000-2003 cases of calcium intoxication, comparable to vitamin D toxicity reported in grazing animals in some parts of the world due to the consumption of some specific native plants.

Presence of Vitamin D_3 and its metabolites in plants: The quest for identifying vitamin D3 or its metabolites in plants was started, when Wasserman, a professor of veterinary medicine and a research scientist with his team tested *Solanum malacoxylon* for its principle component causing hyper-vitaminosis-D like activity (calcification) in grazing animals. He published his research findings in 1976 in Science (New York, N.Y.) journal, where he mentioned the principle component of calcification in animals to be "1, 25 dihydroxy vitamin D_3," the active form of vitamin D_3. Wasserman used a combined gas chromatography and mass spectrometry method for identifying 1, 25-dihydroxy vitamin D_3 (Wasserman *et al*., 1976). Apart from 1, 25-dihydroxyvitamin D_3, *S. malacoxylon* leaves were also reported to contain two other glycoside derivatives of vitamin D_3 (cholecalciferol, and 25-hydroxy vitamin D_3), which served as the irst direct evidence of hydroxylation of vitamin D_3 in plants. Once more in 1996 A different team of scientists separated and measured cholecalciferol, 25-hydroxycholecalciferol, and seven dehydrocholesterol from callus cultures taken from *S. malacoxylon* sterile leaves. The same study's findings demonstrated that media calcium levels have a favorable impact on the callus culture's production of cholecalciferol and 25 hydroxy-cholecalciferolin, highlighting the significance of calcium availability and light in the synthesis of vitamin D3 or its metabolites in plants. Furthermore, the existence of vitamin D_3 in *S. glaucophyllum* leaves is independent of light, defying common wisdom regarding the synthesis of vitamin D_3 in plants. The presence of vitamin D_3 or its metabolites was also examined in other members of the Solanaece family, including *Cestrum diurnum* L., *Lycopersicon esculentum*, *Solanum tuberosum*, *Nicotiana glauca* and *S. melongena*. Free cholecalciferol, 25-hydroxy cholecalciferol, and 1, 25-dihydroxy cholecalciferol were found in the *Cestrum diurnum* plant in concentrations of 0.102 g g^{-1} dry weight, 0.102 g g^{-1} dry weight, and 1 g g^{-1} dry weight, respectively (Prema and Raghuramulu, 1994). Plants from families other than Solanaceae had also shown considerable amount of vitamin D_3 or its metabolites suggesting its presence all over plant kingdom. According to literature vitamin-D_3/ cholecalciferol was first quantified in the dried leaves of yellow oat grass (*Trisetum lavescens* Beauv.) or golden grass of Poaceae family and reported of dried leaf sample.

Presence of Vitamin D_2 in Plants: The discovery of vitamin D_2 in plants dates back to 1925. According to reports, it was initially separated from a UV-irradiated ergosterol solution and subsequently identified as the plant form of vitamin D. When provitamin ergosterol is exposed to UV light, a temperature-dependent thermal isomerization mechanism transforms it into active vitamin D_2. Thus, a number of study assessed the potential use of non-animal food sources high in ergosterol as a dietary source of vitamin D. Prior to 2000, two important studies quantified the amount of vitamin D_2 in grains and vegetables, according to the literature. Horst carried out the first investigation of vitamin D_2 quantification on the Fabaceae family plant, *Medicago sativa* (alfalfa). In 2018, a different German study team discovered that raw cocoa beans contained 0.20 µg of vitamin D_2 per 100 g of fresh weight. Additionally, they measured the amount of vitamin D_2 in various chocolates and found that the concentrations of vitamin D_2 in dark chocolate, white chocolate, and chocolate nut spreads were (1.90-5.48) µg/100 g, (0.19-1.91) µg/100 g, and 0.15 µg/100 g of chocolate, respectively (Kuhn *et al*., 2018).

Conclusion

We now know that vitamin D may also be present in fruits and vegetables. Previously, it was thought that vitamin D_3 could only be found in animal products. It is especially noteworthy that the Solanaceae family contains significant quantities of vitamin D_3, given the importance of this family in human diet. Common vegetables from this family, such as potatoes, tomatoes, and peppers, are used in every kitchen and have been shown to contain vitamin D_3, but only in their leaves. As a result, it is now challenging for academics to look into new uses for them.

References

Bailey, R. L., Dodd, K. W., Goldman, J. A., Gahche, J. J., Dwyer, J. T., Moshfegh, A. J., ... and Picciano, M. F. (2010). Estimation of total usual calcium and vitamin D intakes in the United States. *The Journal of Nutrition*, 140 (4): 817-822.

Chick, H., Dalyell, E., Hume, M., Smith, H. H., Mackay, H. M., Wimberger, H. and Kinderklinik, R. T. T. U. (1922). The aetiology of rickets in infants: prophylactic and curative observations at the Vienna University Kinderklinik. *The Lancet*, 200 (5157): 7-11.

Holick, M. F. (2011). Vitamin D: a d-lightful solution for health. *Journal of Investigative Medicine*, 59(6): 872-880.

Kühn, J., Schröter, A., Hartmann, B. M. and Stangl, G. I. (2018). Cocoa and chocolate are sources of vitamin D_2. *Food Cemistry*, 269: 318-320.

Jakobsen, J., Maribo, H., Bysted, A., Sommer, H. M. and Hels, O. (2007). 25-Hydroxyvitamin D_3 affects vitamin D status similar to vitamin D_3 in pigs but the meat produced has a lower content of vitamin D. *British Journal of Nutrition*, 98(5): 908-913.

Kendrick, J., Targher, G., Smits, G. and Chonchol, M. (2009). 25-Hydroxyvitamin D deficiency is independently associated with cardio-vascular disease in the Third National Health and Nutrition Examination Survey. *Athero-sclerosis*, 205(1): 255-260.

Prema, T. P. and Raghuramulu, N. (1994). Free vitamin D_3 metabolites in *Cestrum diurnum* leaves. *Phytochemistry*, 37(3): 677-681.

Wasserman, R. H., Henion, J. D., Haussler, M. R. and McCain, T. A. (1976). Calcinogenic factor in Solanum malacoxylon: evidence that it is 1, 25-dihydroxyvitamin D_3 glycoside *Science*, 194(4267): 853-855.

Fruits as a Source of Natural Food Colours, Biochemical Constitutes and Pigments

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Introduction

Eating fresh fruits is a major source for people to intake natural nutrients; beyond that, fruit can also be fermented or processed into fruit wine, fruit juice, preserved fruit and other products for consumption. Fruits contain a variety of natural pigments, which are secondary metabolites with important biological activities (Karppinen *et al.*, 2016). In addition, fruit color is also an important commodity quality that determines the consumers' choice. These pigments play essential roles in plant growth and development, photosynthesis, attracting pollinators and seed carriers, and resisting biotic and/or abiotic stresses. Since pigments are found in all living things, and plants are the primary source of pigments, they create the colors we see throughout our lives manufacturers. In addition to being found in skin, eyes, and other animal tissues, they are also found in bacteria, fungi, leaves, fruits, vegetables, and flowers. Pharmaceuticals, meals, clothing, furnishings, cosmetics, and other goods all contain both natural and manufactured hues. The visible spectrum of red, orange, yellow, green, blue, indigo, and violet is represented by wavelengths between about 380 and 730 nm, which are detectable by humans without color blindness. Therefore, chloro-phyll will leave wavelengths that constitute a green color because its highest absorbencies are at 430 and 680 nm. A mixture of leftover wavelengths frequ-ently produces the colors; for instance, antho-cyaninsm that absorbs yellow-green light with wavelengths between 520 and 530 nm would produce mauve hues by the reflection of a mixture of orange, red, and blue wavelengths.

Plant pigment-ation is generated by the electronic structure of the pigment interacting with sunlight to alter the wavelengths that are either transmitted or reflected by the plant tissue. The specific colour perceived will depend on the abilities of the observer.

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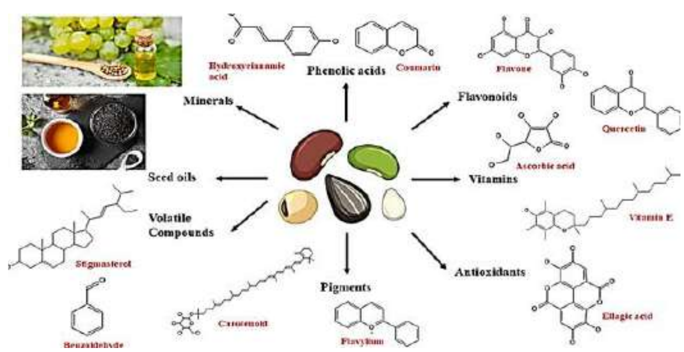
In recent decades, there has been growing interest in the identification and characterization of high added value extracts from natural sources that are capable of providing additional benefits to human health. Fruits are renowned for their vivid and varied hues, which are produced by a range of organic pigments. These pigments are chemical substances that give fruits their unique colors by absorbing and reflecting light at particular wavelengths. From reds and yellows to purples and greens, each pigment represents a distinct color in the visible spectrum. These hues have significant biological purposes for plants in addition to being aesthetically pleasing. When these natural pigments are utilized as food colorants, they are typically classified based on their chemical structure and the specific colors they produce. The most commonly used fruit-derived pigments in the food industry are carotenoids, anthocyanins, betalains, and chlorophylls.

Carotenoids: Carotenoids are natural pigments that give many fruits their yellow, orange, and red hues. These fat-soluble compounds are known for their antioxidant properties, which contribute to their health benefits. Carotenoids include substances like beta-carotene, lutein, zeaxanthin, and lycopene, and can be found in fruits such as carrots, pumpkins, oranges, and tomatoes. For instance, beta-carotene gives carrots and sweet potatoes their orange color and is a precursor to vitamin A, a crucial nutrient for vision and immune health. Lycopene, present in and watermelon, has been linked to a lower risk of heart disease and cancer. The antioxidant effects of carotenoids add to their appeal as natural food colorants. In nature, fruits have lesser xanthophyll contents compared to vegetables. Some fruits such as papaya (*Carica papaya* L.) and persimmon (*Diospyros* sp.) have high amount of xanthophylls (lutein and zeaxanthin), like that found in vegetables. In fruits and vegetables, β-carotene is found to be bound to either chlorophylls or xanthophylls, forming chlorophyll-carotenoid complexes, which absorb light in the orange or red light spectrum and give rise to green, purple or blue coloration. Carotenoids provide colors to flowers, seeds, fruits and to some fungi and colour has an important role in reproduction: coloration attracts animals that disperse pollen, seeds, or spores. In *Phycomyces blakesleanus* it was observed that intracellular accumulation of excess Carotenoids disturb the mating recognition system, which appears to be involved in the later stages of mating by inhibiting the cell-to-cell recognition systems (Delgado-Vargas *et al*., 2000).



Anthocyanins: Anthocyanins are water-soluble pigments that impart red, blue, and purple colors to fruits. Anthocyanins, a subgroup of flavonoids, are plentiful in fruits such as blueberries, blackberries, cherries, and grapes. Beyond coloring fruits, they also possess strong antioxidant and antiinflammatory properties. Research suggests that anthocyanins can help lower the risk of cardiovascular disease, enhance cognitive function, and provide anti-cancer effects. Anthocyanins are sensitive to changes in pH and environmental factors, which can influence their color. In acidic conditions, anthocyanins appear red, whereas in alkaline conditions, they can change to blue or purple. This sensitivity makes anthocyanins adaptable for use in various food products such as beverages, confectioneries, and dairy items. In solution, anthocyanin molecules are present in equilibrium between the colored cationic form and the colorless pseudobase. This equilibrium is directly influenced by pH. Acidic pH is favorable for the colored form that diminished with pH increments. Some anthocyanins are red in acid solutions, violet or purple in neutral solutions, and blue in alkaline pH. This is the reason that most colorants containing anthocyanins can only be used at pH values below four (Delgado-Vargas *et al*., 2000).

Betalains: Water-soluble pigments called betalains give several fruits and vegetables their red, purple, and yellow hues. Foods like beets, prickly pears, and some varieties of plums contain them. Betacyanins, which give red and purple hues, and betaxanthins, which provide yellow and orange tones, are the two types of betalains. In addition to their well-known antioxidant advantages, betalains-especially betacy-anins-have been shown to possess neuroprotective, anti-inflammatory and anti-cancer qualities. Althou-gh betalains are not as prevalent as carotenoids and anthocyanins in fruits, they are gaining traction as natural food colorants due to their distinctive colors and health-promoting qualities. For example, beet juice, which is rich in betalains, is increasingly being used as a natural colorant in the beverage and confectionery sectors.

Chlorophyll: Chlorophyll is the green pigment found in the chloroplasts of plant cells, giving many fruits and vegetables their green color. While it is most commonly associated with leafy vegetables, chlorophyll is also found in fruits like kiwis and green grapes. Chlorophyll has antioxidant properties and has been researched for its potential benefits in detoxification and cancer prevention. However, its use as a food colorant is less widespread than carotenoids and anthocyanins, as chlorophyll is more prone to degradation during processing and storage.

Health Benefits of Fruit-Derived Pigments

One of the key advantages of using fruit-derived pigments as food colorants is that they not only enhance the visual appeal of food but also provide several health benefits. Many of the pigments present in fruits are bioactive compounds that have been shown to positively impact human health. These benefits include:

Antioxidant Properties: The antioxidant qualities of many fruit pigments, particularly carotenoids and anthocyanins, are well known. Antioxidants aid in the neutralization of free radicals, which can harm cells, accelerate aging, and contribute to the emergence of chronic illnesses like cancer and heart disease.

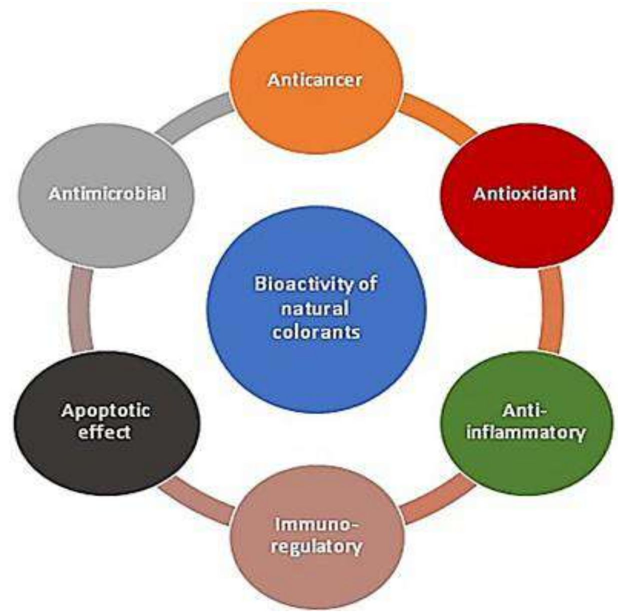
Anti-Inflammatory Benefits: Particularly anthocyanins and betalains have demonstrated the ability to reduce inflammation in the body. This anti-inflammatory action can help in preventing or managing conditions such as arthritis and cardio-vascular diseases.

Eye Health Support: Carotenoids like beta-carotene and lutein are well known for promoting eye health by protecting the retina from oxidative stress and reducing the risk of age related macular degen-eration.

Cardiovascular Health: Consuming fruits rich in anthocyanins, such as berries, has been linked to a reduced risk of heart disease. These pigments assist in enhancing blood vessel function, reducing blood pressure, and lowering LDL cholesterol levels.

Natural food colourants

The quality of food is firstly assessed by its visual characteristics such as colour. Fresh food is highly coloured by the major plant pigment groups, like carotenoids and anthocyanins in fruit and chlorophylls in green vegetables. However, the pigmentation is often lost during manufacturing of processed foods and the visual appeal of the final product is enhanced using added colourants. Before the discovery of synthetic dyes, the food industry was solely reliant on natural food colourants. The use of natural colourants in many applications was superseded by synthetic dyes, in recent years industries has been returned to use the natural colourants with increased interest in new and improved sources in food applications. Plant pigment widely used as food colourants are: annatto, antho-cyanins, betalains (beetroot pigment) and curcumin (turmeric pigment). Together with the insect-derived pigment cochineal, they account for over 90% of the market for natural food colourants Use of chlorophyll as a food colourant is very limited in comparison to these pigments, principally because of its poor stability during food processing or in response to light or acid conditions in the final food product.



Biochemical Constituents of Fruits

Fruits contain a large percentage of water, which can often exceed 95% by fresh weight. During ripening, activation of several metabolic pathways often leads to drastic changes in the biochemical composition of fruits. Fruits such as banana store starch during development, and hydrolyze the starch to sugars during ripening, which also results in fruit softening. Most fruits are capable of photosynthesis, store starch, and convert starches to sugars during ripen ing. Fruits such as apple, tomato, and grape have a high percentage of organic acids, which decreases during ripening. Fruits contain large amounts of fibrous materials such as cellulose and pectin. The degradation of these polymers into smaller water soluble units during ripening leads to fruit softening, as exemplified by the breakdown of pectin in tomato and cellulose in avocado. Secondary plant products are major compositional ingredients in fruits. Anthocyanins are the major color components in grapes, blueberries, apples, and plums; carotenoids, specifically lycopene and carotene, are the major components that impart color in tomatoes.

Conclusion

A tasty and healthful substitute for artificial food coloring, fruits are a rich and diverse source of natural hues. Fruit-derived pigments including carotenoids, anthocyanins, betalains, and chlorophyll give food products both aesthetic and functional advantages with their variety of colors and bioactive qualities. Fruit-based colorants have a bright future, despite ongoing difficulties with stability, cost, and regulations. The goal of ongoing research is to get over these obstacles and increase their application in the food sector. It is undoubtedly possible to expand the shade range of natural dyes with good coloring qualities by investigating new dye sources. Nevertheless, thorough studies on the security of these materials to people and the environment before promoting their use, since natural materials might not always be safe. Since dangerous compounds are also known to be produced by nature, comprehensive toxicological analyses of the new sources are required.

References

Karppinen, K., Zoratti, L., Nguyenquynh, N., Häggman, H. and Jaakola, L. (2016). On the developmental and environmental regulation of secondary metabolism in *Vaccinium spp*. berries. *Frontiers in Plant Science*, 7: 655.

Delgado-Vargas, F., Jiménez, A. R. and Paredes-López, O. (2000). Natural pigments: carotenoids, anthocyanins, and betalains characteristics, biosynthesis, processing, and stability. *Critical Reviews in Food Science and Nutrition*, 40(3): 173-289.

Spider Silk Nature's Marvelous Material

Manda Anil Mhatre, Vinda Manjramkar and Khan Laiqur Rehman Moiz

Introduction

In the past, spiders were considered as mysterious or dangerous animals and numerous beliefs were linked to them; this state of mind was particularly developed in the last century, even in scientific circles. Therefore, acquisition of know-ledge of the biology, ecology and taxonomy of spiders has been considerably delayed compared with that relating to other groups, e.g. insects. The many ecological field studies carried out in the past decades have allowed the emergence of numerous new faunistical and biological data on spiders. As has been developed in this chapter, this specific information on spiders constitutes the basis for any field survey dealing with biological control or bioindicators. Spiders, belonging to the class Arachnida under phylum Arthropoda, are ubiquitous in various habitats, making them the most abundant invertebrate predators on land. With a history spanning 300 million years, they encompass around 47,617 species globally, with 2,299 in South Asia and 1,442 in India alone. Spider silks, proteinaceous filaments secreted by specialized abdominal glands of Araneomorphae, form one of the main hallmarks of biomimetism. Dragline silk plays this role for long because this thread is renowned for its startling mechanical properties: a combination of strength and extensibility that provides an incomparable tough-ness and outclasses any industrial material (Sanchez *et al*., 2005). These performances make spider silk the subject of intense research and position it as a very attractive biomaterial for future applications. Silk fibers are protein-based biopolymer filaments or threads secreted by specialized abdominal glands connected to the spinnerets, ducts or spigots, and are used in different combinations to produce structures for prey capture, reproduction and locomotion. Exceptionally complex spinning processes are used by the spider to transform soluble silk proteins into solid fibers with specific mechanical and functional properties. Spider silk is spun near ambient temperatures and pressures using water as the solvent, which gives rise to an environmentally safe, biodegradable material (Asakura and Kaplan, 1994).

Spider silk types and glands

Up to six distinct types of silk, together with

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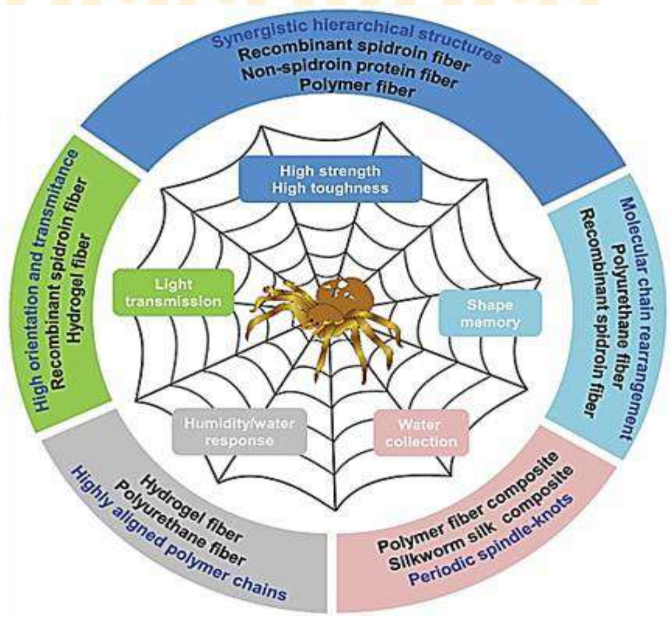
a glue substance that serves a variety of biological purposes, can be produced by orb web spiders. The various seven morphologically different silk glands exhibit restricted expression of silk types, which are protein-based polymers belonging to the spider silk protein superfamily. It is believed that these several abdominal glands diverged in their appearance, luminal contents, and architecture after evolving from a single type of gland. It is suggested that the silk proteins in each gland are put together to form distinct fibers with unique roles based on the varying amino acid compositions of the luminal contents. The primary ampullate gland, which produces the components of dragline silk, has been the subject of the majority of research to far. Dragline silk is renowned for combining elasticity and high tensile strength to create a fiber with exceptional toughness. Dragline silk is used by spiders to make safety lines and web anchors. The minor ampullate gland, which is morphologically identical to the major ampullate, produces temporary capture silk and web radii filaments. Other abdomen glands, including as the flagelliform, aggregation, and aciniform glands, create different kinds of silk that take part in the direct capture of prey. Capture silk, also known as viscid silk, is a composite silk that contains material derived from the flagelliform and aggregate glands. Flagelliform gland silk is extremely ex tensible and forms the capture spiral of an orb web; this elasticity has been proposed to facilitate prey capture, enabling webs to arrest the motion of flying organisms without breaking.

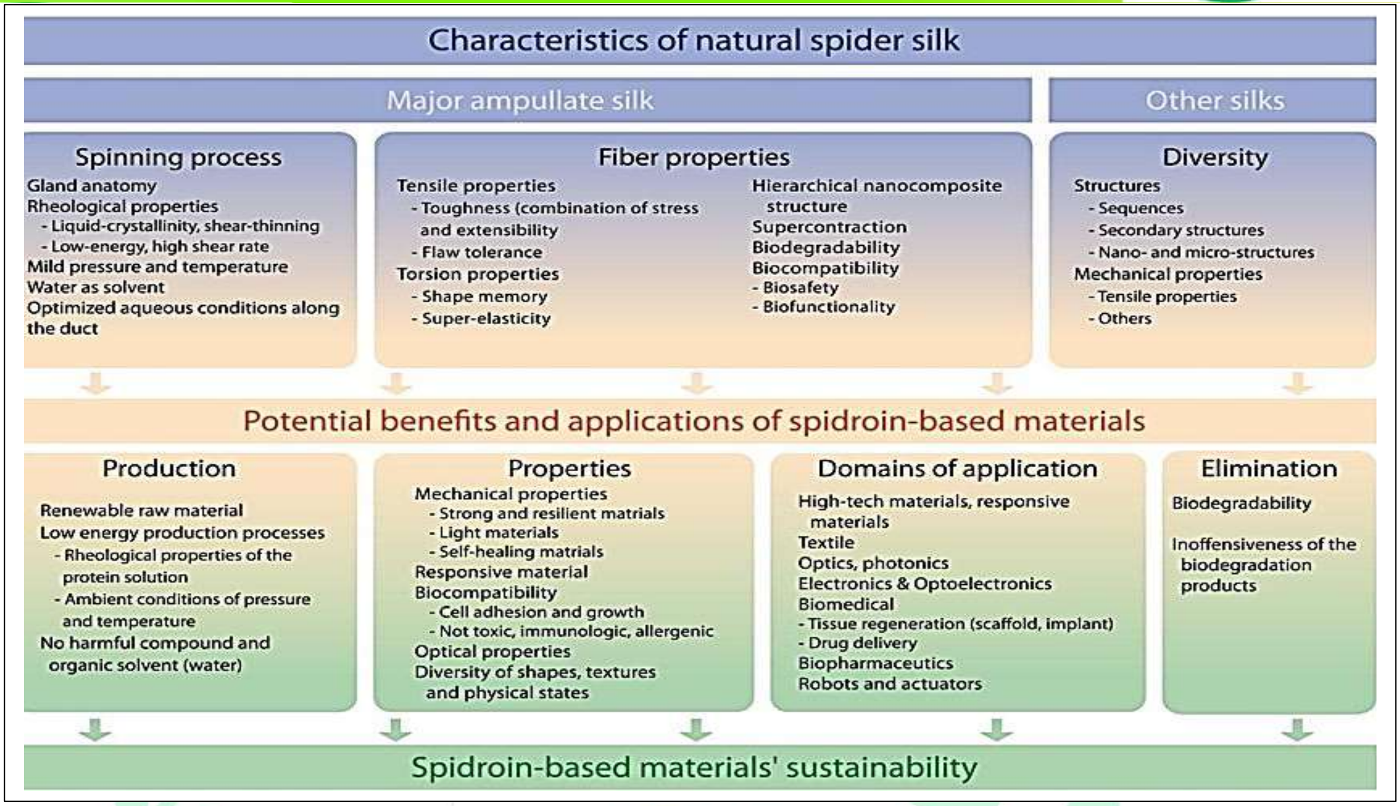
A Marvel of Nature: Stronger than Steel more Elastic than Rubber

Chemically, spider silk is semi-crystalline in nature having properties like high tensile strength and elasticity. This structure allows it to absorb more energy before reaching the point of breakage. Spider silk is known to possess high strength of 1.75 GPa at a breaking elongation of over 26%. On weight by weigh basis, spider silk is five times stronger than steel, three times toughest to Kelvar and two times more flexible than nylon. The unique strength and flexibility of spider silk make it an ideal biomaterial for making parachutes and body armor. Apart from this, the properties like biocompatibility and biodegradability makes it a suitable for biomaterial for biomedical applications.



Role of Biotechnology: Spining Spider Silk without Spiders

Scientists have successfully cloned the spider genes and introduced them into various organisms, from bacteria to goat. Each organism presents its



own set of challenges and advantages; while bacteria like *E. coli* are the fast growing, cost effective but they struggle to produce large sized proteins. Yeast can handle large proteins but they grow slowly and are more expensive. Mammalian like the famous "Spider Goat" can produce huge amount of spider silk in milk but cost remains a major issue. Plants are also being explored as a cost-effective protein factory, promising a sustainable solution to the silk production (Whittall *et al*., 2021).

From Medicine to Aerospace: Spider Silk's Applications

The spider silk possesses quite vast applications. In medical sector, biocompatibility and its strength make it an ideal material for sutures, wound dressings and scaffolds to support tissue growth. Additional, spider silk is being used to create artificial nerve, artificial tendons or ligaments and also as a drug delivery system to specific cells. In material science, its outstanding properties of high tensile strength to weight ratio could transform various industries. From bulletproof vests to aerospace components, spider silk based materials offer superior performance, being lighter and more environmentally sustainable option as compared to the traditional materials. The automobile industry is keen to utilize spider silk to develop stronger and lighter vehicles with improved fuel efficiency (Guessous *et al*., 2024).

Spider Silk and Cutting-Edge Electronics

Spider silk definitely has a lot of potential for use in electronics. Spider silk, which is inherently an insulator, can be made into a conducting material with exceptional qualities by covering it with conductive materials like gold, iodine, or carbon nanotubes. It is capable of adjusting to changes in the environment, such humidity and retaining conductivity at cryogenic temperatures. Furthermore, advances in microelectronics, heat management, and bio-integrated devices may result from the combination of spider silk, nanotechnology, and functional coatings.

Spider Silk in Cosmetic Products

Spider silk has significantly impacted the cosmetics business in a number of ways. Many commercial cosmetic products, including skin and hair care products including lotions, gels, anti-aging creams, dyes, bleaches, cleansers, shampoos, and conditioners, include spider silk proteins as active ingredients. The use of finely chopped silk is what gives my pricey cosmetics their glossy finish.

The Pioneer Companies: Bringing Spider Silk to Markets

As research progressed, a number of businesses led the way in introducing spider silk products to the market. Bolt Threads collaborated with high-end fashion labels like Stella McCartney to develop high-performance textiles in the United States using genetically modified yeast to make their signature MicrosilkTM. The German business AM Silk uses bacterial fermentation to produce fibers and cosmetic components. The Biosteel® fiber from AM Silk is being investigated for a number of uses, including sophisticated medical gadgets and high-performance footwear. In the meantime, QMON OSTM, a high-performance spider silk fiber utilized in automobile and outdoor gear, was created by Japan's Spiber Inc. Kraig Biocraft Laboratories in the U.S. developed a unique approach by creating transgenic silkworms that produce spider silk proteins, leading to Dragon Silk™. Meanwhile, Spider Silk Industries in France majorly focussing on medical applications like tissue engineering and drug delivery, highlighting it's potential to revolutionize healthcare industry (Zhang *et al*., 2021).

Application of High Tech Threads

Since natural spider fibers have a wide range of amazing mechanical properties, some of which are better than those of industrial fibers, many attempts are made to create "strong" fibers like the ones seen above. Therefore, it is likely that a number of applications will focus on creating different specialty threads or using synthetic spider silk strands in these high-tech filaments. Synthetic spider silk has a wide range of potential applications in the future, including parachute cord, bulletproof vests, specialty rope (for the sports or textile industries), fishing nets, and reinforcement materials for polymer matrices, such as those used in the aviation sector (Numata *et al*., 2010).

Textile: The textile industry has a long history of using the silk made by the mulberry silkworm, *B. mori*. Its smooth feel texture, shine, drapability, and mechanical strength make it highly valued. However, it has a number of disadvantages, including UV-induced yellowing, wrinkling, deterioration, and low wet resilience. Spider silk materials may potentially spark interest in the textile industry to create fibers with unique qualities like dyeing (colored and luminous fibers) or multifunctionality.

Biomedicine: Products made from spider silk might not be financially feasible in the near future since the raw material's supply is still a major issue. At the very least, a high manufacturing cost may be expected, particularly given the potential difficulty of achieving large-scale production and the need for multi-step purifying processes. Therefore, the first potential uses of spider silk-based materials where specifically load-resistant fibers are needed are likely to be in specialist areas, especially in the biomedical industry.

Optics and Electronics: Interesting optical, photonic and electrical responses can also be seen in silk. The use of silkworm silk in this field of study has proven successful, and it is possible that proteins connected to spider silk will also contribute significantly. Surface nanopatterning has made it possible to create optically transparent fiber materials that, when the f-sheet composition is controlled, can produce bioactive devices for optical applications such diffraction gratings, pattern generators, and lenses in particular. Optical waveguides have been created using the "direct ink writing" technique, opening up new possibilities for the development of biophotonic elements that are easily functionalized or doped with biologically active substances.

Conclusion

There aren't many examples of materials produced by nature that can be compared to the fabrication timelines of humans. One uncommon natural model that scientists can use as inspiration is silk. Silk, like other natural materials, seems to be an incredible compromise between these seemingly incompatible qualities, whereas synthetic materials typically have to choose between strength and extensibility. Furthermore, the soft watery environ-ment of the spinning gland gradually modifies the mechanically induced assembly response of the very simple constituents that make up silk, namely spidroins. The future of spider silk seems promising and likely to become more accessible and widespread. Innovative applications ranging from biodegradable sensors to artificial blood vessels, are continuously being discovered. Its unique properties make it ideal to be exploited in the fields like medicine, electronics and environmental conserv-ation, there by bridging how natural systems can cater future needs.

References

Sanchez, C., Arribart, H. and Giraud Guille, M. M. (2005). Biomimetism and bioinspiration as tools for the design of innovative materials and systems. *Nature Materials*, 4(4): 277-288.

Asakura, T. and Kaplan, D. (1994) Silk production and processing. *Encyclopedia of Agricultural Science*, 4: 1-11.

Zhang, Q., Li, M., Hu, W., Wang, X. and Hu, J. (2021). Spidroin-Based Biomaterials in Tissue Engineering: General Approaches and Potential Stem Cell Therapies. *Stem Cells International*, 2021(1): 7141550.

Whittall, D. R., Baker, K. V., Breitling, R. and Takano, E. (2021). Host systems for the production of recombinant spider silk. *Trends in Biotechnology*, 39(6): 560-573.

Numata, K., Cebe, P. and Kaplan, D. L. (2010). Mechanism of enzymatic degradation of beta-sheet crystals. *Biomaterials*, 31(10): 2926-2933.

Artificial Intelligence in Plant-Soil-Microbe Interactions

Manisha Rani, Ramachandra Naik M. and Premsagar Nishad

Introduction

Agriculture forms the foundation of human society, relying on the highly dynamic and intricate interactions between soils and plants. These interactions strongly influence nutrient supply, soil structure, plant growth, and overall crop health (Khan *et al.*, 2023). Sustainable crop production depends on a thorough understanding of these complex processes to maximize productivity while preserving soil health and environmental stability. Advances in soil science over the past few decades have highlighted the essential roles of microbial communities, nutrient cycling and root-soil interactions in achieving sustainable agriculture (Das *et al.*, 2022). Plant-microbe interactions can have both beneficial and harmful effects on plant development. When microbial activity negatively impacts plant growth, it is considered antagonistic or detrimental. Conversely, when microbial associations enhance plant survival, improve nutrient uptake, and boost crop yields, the relationship is regarded as synergistic or beneficial. A harmonious and balanced relationship between soil microorganisms and plant systems is essential for maintaining and improving soil health for long-term sustainability. A vital component of maintaining human existence, soil is a limited and irreplaceable natural resource. Large-scale soil degradation has been greatly exacerbated over the past few decades by the global intensification of agricultural methods brought on by the rising need for food. Soil fertility has decreased, water retention capacity has decreased, organic carbon has been depleted, biodiversity has been lost, and vital nutrient cycling processes have been disrupted as a result of this degradation. Complex interactions between plants, soil components and micro-organisms have a significant impact on the health and productivity of soil (Kumar and Verma, 2019). Numerous interactions occur between soil micro-organisms, such as bacteria, fungus, and other microscopic life forms, and plant roots (Xing *et al.*, 2025). A vital component of maintaining human existence, soil is a limited and irreplaceable natural resource. Large-scale soil degradation has been greatly exacerbated over the past few decades by the global intensification of agricultural methods brought on by the rising need for food. Soil fertility has decreased, water retention capacity has decreased, organic carbon has been depleted, biodiversity has been lost, and vital nutrient cycling processes have been disrupted as a result of this degradation. Complex interactions between plants, soil compone-

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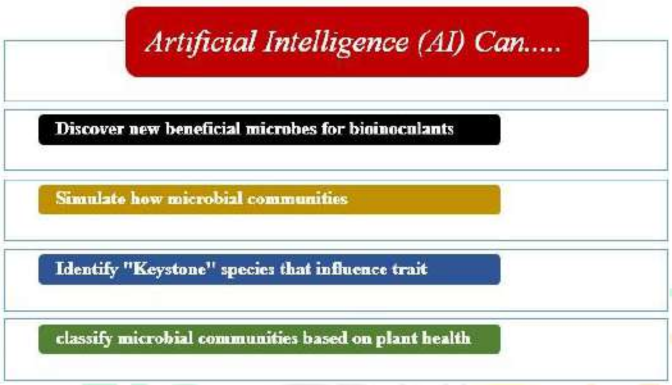
nts, and microorganisms have a significant impact on the health and productivity of soil. Numerous interactions occur between soil microorganisms, such as bacteria, fungus, and other microscopic life forms, and plant roots. These interactions support a wide range of biological processes that are critical for maintaining ecological balance and sustainability within soil environment. These biological players have co-evolved over millions of years, forming a complex underground network of interactions essential for crop health, ecosystem balance, and food security. But understanding this intricate web is no small feat. Artificial Intelligence (AI), a tool that is revolutionizing how we decode, analyze, and harness the invisible partnerships between soil, microbes, and plants. From improving crop productivity to reducing chemical dependency, AI is emerging as a game-changer in agroecology.

Artificial Intelligence: Interpreting Microbial Intricacy

By making it easier to integrate and analyze complex, high-dimensional biological data, artificial intelligence (AI) is revolutionizing omics. A thorough understanding of plant-soil-microbe interactions is provided by genomics, transcriptomics, proteomics, and metabolomics. But every omics layer generates a lot of varied data, requiring the application of sophisticated instruments to derive important biological conclusions. AI is essential for combining these datasets and identifying host-microbe interactions, microbial community functions and biological processes. In order to understand systems biology, multi-omics integration uses analytical frameworks that combine data from many omics layers. Nonlinear high-order interactions between genes, proteins, and metabolites are frequently difficult to detect using conventional statistical techniques. Deep learning algorithms in particular have shown promise in identifying intricate patterns and connections within large datasets. Pathway and network reconstruction is another area in which AI shows great potential. By combining functional gene annotations and molecular expression data, AI can map the gene regulatory networks and metabolic pathways that control soil microbiome behavior and plant responses. For example, unsupervised learning models, such as auto-encoders, assist in compressing and visualizing high-dimensional omics data, whereas supervised methods predict gene or protein functions based on existing databases. Biomarker discovery is essential for diagnosing and monitoring plant and soil health. AI aids in feature selection and classification from omics datasets to identify molecular signatures that indicate disease resistance, stress tolerance and beneficial microbial colonization. These biomarkers are potential targets for breeding and microbial inoculation strategies in sustainable agriculture. Overall, AI-driven omics integration not only deepens our understanding of biological systems but also accelerates the development of microbiome-informed agricultural practices. The fusion of AI and multi-omics will lead to precision interventions that are both predictive and tailored to specific plant-soil-microbe ecosystems.

Researchers now use AI to integrate data from

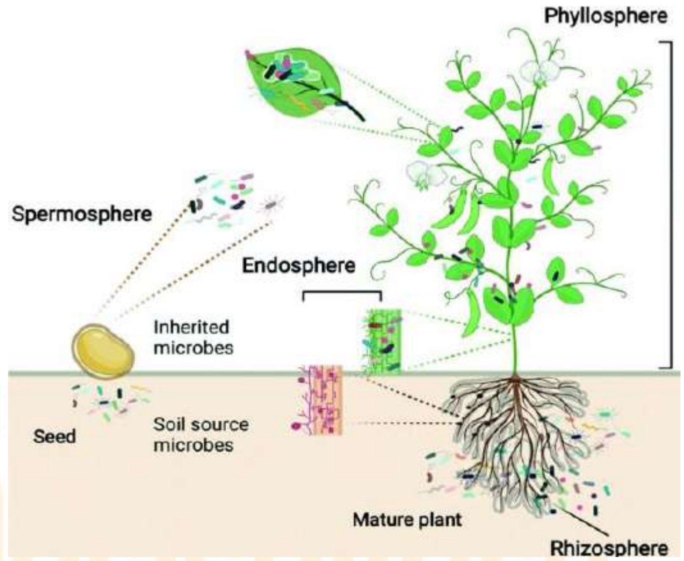
- ✓ Plant phenomics (How are plants responding?)
- ✓ Environmental sensors (What are the soil, moisture, and weather conditions?)
- ✓ Metabolomics (What are they producing?)
- ✓ Metatranscriptomics (What are they doing?)
- ✓ Metagenomics (Who's there?)



Real-World Use Cases: AI in Action

Microbial Signatures for Disease and Stress: AI and ML models analyze microbiome profiles to identify microbial signatures linked to disease suppression and stress tolerance. Algorithms like SVM, random forests, and deep learning can detect biomarkers that predict plant health status. This enables early diagnosis of soil-borne pathogens such as *Fusarium oxysporum*, *Ralstonia solanacearum*, and *Pythium ultimum*, often before symptoms appear. Such precision diagnostics support timely interventions and guide the development of synthetic microbial consortia for improved resilience (Pace *et al.*, 2025).

Soil Health Indexing: Soil health depends not only on nutrients but also on microbial diversity and activity. AI-based models, combined with biosensors and portable sequencing tools, enable real-time monitoring of microbial indicators. Integrated into decision support systems, these tools provide site-specific recommendations for amendments, crop rotation, and tillage, making Soil Health Indexing more predictive and sustainable at field scale.



Custom Bio-fertilizer Development: Bio-fertilizers that are customized for particular soil, crop, and environmental circumstances are rapidly being produced using AI technologies. Researchers can identify plant growth-promoting bacteria (PGPB) with the most potential to increase production and resilience by combining multi-omics data, systematic screening, and multi-phase validation from laboratory to field. For instance, studies on crops like strawberries have demonstrated how data-driven methods can enhance targeted microbial selection. AI models, such as random forests and neural networks, are now employed to predict essential microbial functions, such as phosphate solubilization or nitrogen fixation, allowing indus-tries to design custom bio-inoculants that significantly outperform generic ones in practical agricultural environments.

Decision Support in Precision Agriculture: Integrating AI with IoT sensors, drones, and satellite imagery allows for field-level decisions. A farmer can know when and where to apply biofertilizers, irrigate, or rotate crops based on microbial activity patterns.

Climate Adaptation and Carbon Sequestration: Certain microbes increase plant resilience to drought, heat, or salinity. AI models can identify such species and simulate their long-term impact on soil carbon storage supporting regenerative agriculture and climate mitigation.

Future Directions: Toward a Living Agriculture

Imagine a time when drones spray location-specific probiotics instead of pesticides, or when AI-powered soil tests instantaneously recommend microbial blends for your crop. Similar to how doctors examine our gut microbiomes, farmers may keep an eye on the microbiome of their soil. AI-guided regenerative farming, microbiome-assisted crop breeding, digital soil passports, and living fertilizers and biopesticides are all made possible by the combination of soil biology and AI.

Conclusion

The convergence of AI and microbial ecology is ushering in a new era of intelligent, resilient, and nature aligned farming. We are no longer just cultivating crops; we are nurturing entire ecosystems. As we begin to interpret the silent signals of microbes through the lens of AI, agriculture is transforming from a struggle against nature into a more harmonious and informed collaboration with it.

References

Das, P. P., Singh, K. R., Nagpure, G., Mansoori, A., Singh, R. P., Ghazi, I. A., ... and Singh, J. (2022). Plant-soil-microbes: A tripartite interaction for nutrient acquisition and better plant growth for sustainable agricultural practices. *Environmental Research*, 214: 113

Khan, D., Kabiraj, A., Biswas, R., Roy, R. K. and Bandopadhyay, R. (2023). Plant-microbe community dynamics in rhizosphere: reviewing the grassroots ecology towards sustainable agriculture. *The Indian Journal of Agricultural Sciences*, 93(3): 247-257.

Xing, Y., Wang, X. and Mustafa, A. (2025). Exploring the link between soil health and crop productivity. *Ecotoxicology and Environmental Safety*, 289: 117703.

Pace, R., Schiano Di Cola, V., Monti, M. M., Affinito, A., Cuomo, S., Loreto, F. and Ruocco, M. (2025). Artificial intelligence in soil microbiome analysis: A potential application in predicting and enhancing soil health a review. *Discover Applied Sciences*, 7(2): 85.

Improved Technologies for Sustaining Productivity and Profitability of Sheep in India

Michelle C. Lallawmkimi, Shilpi Priya Sunita Bara and Jessy Bagh

Introduction

Livestock, an integral component of the agriculture and allied sector, contributes 28.4% Gross Value Added (GVA) to agriculture and allied sector which is equivalent to 4.9% of total GVA. Though the contribution of agriculture and allied sector, as a whole, to total GVA is declining over the years, the share of the livestock sector to agricultural GVA and total GVA is showing an increasing trend. It suggests that the cattle industry's contribution to the national economy is steadily growing in significance. In practically every climate in the nation, from the hot and dry climate of Rajasthan and Gujarat to the cold climate of Jammu and Kashmir and Himachal Pradesh to the hot and humid climate of Odisha and West Bengal, poor farmers rely on sheep husbandry as a source of income and livelihood. Small animals like sheep, goats, pigs, and backyard chickens are valued from the standpoint of the impoverished due to their low beginning costs, nil or little input requirements, and rapid returns on investment over time (Birthal *et al*. 2003). Raising sheep provides a buffer during times of adversity, such as drought and famine, particularly for the less fortunate and socially isolated segments of society. It is a source of revenue creation and household nutrition, as well as movable assets with high liquidity. By 2030, the demand for meat is predicted to reach 15 million tonnes, of which 0.58 million tonnes, or 5%, will come from sheep. Sheep is one of the most important livestock species providing food and nutritional security to a large resource-scarce section of the human population of India belonging to the small, marginal farmers and landless labourers. Sheep farming, which needs less initial investment, is suitable for a low input system, and adapted to adverse climatic conditions. Thus, it is an important tool of poverty alleviation. Sheep are contributing to the livestock sector through the production of mutton, wool, milk, skin, manure, etc. Besides domestic consumption mutton is being exported to foreign countries. Sheep also produce skin, manure, and a small amount of milk in addition to mutton and wool. Sheep skin is exported in the form of leather and leather products, in addition to its domestic use. Agricultural activities use sheep manure.

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Some sheep breeds that produce a higher amount of milk are milked and sold as whole milk or milk products. Production data of Indian sheep for these traits are not available.

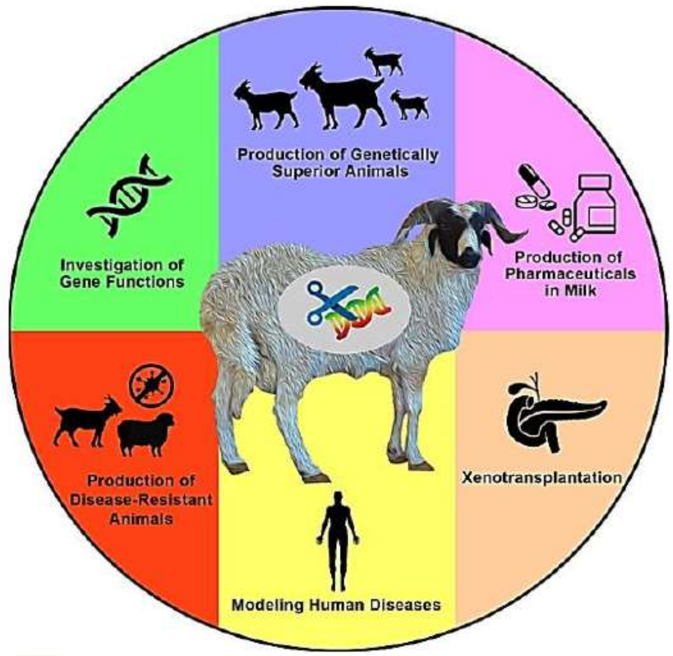
Low Productivity in Sheep Due to Degraded Grazing Lands

Mortality was higher in sheep flocks as a result of the animals' delayed heat signs and occasional silent heat episodes brought on by inadequate nutrition. According to Tewari and Arya (2005), land degradation has been made worse by intense grazing pressures on the parched Rajasthani rangelands. The livestock pressure, measured in adult cattle units (ACU), rose from 9.58 million in 1983 to 11.27 million in 2001. With minimal additional concentrate food, sheep and goats fared better in adverse climates than other animals. According to Suresh *et al*. (2010), farmers believe that the pastureland's degradation has led to a decrease in sheep's animal body weight (20%) and wool yield (18%). When compared to regular monsoon seasons, the death rate among sheep flocks increased noticeably during drought years. Sheep suffered from ectoparasites and protozoa because preventive measures were not promptly adjusted. Compared to regular monsoon years, drought years saw harsher pasture grazing conditions. Farmers' flocks of sheep urgently need to have their nutritional needs met with a balanced diet.

Technological Advancement in Sheep Farming

Sheep Nutrition: Sheep have a special capacity to live off of natural grasses, bushes, and agricultural wastes like field leftovers. Unfortunately, the production of sheep for the purpose of grazing is seriously threatened by the lack of feeds and pasture due to the shrinkage of grazing fields and their degradation. Reduced flock sizes and the loss of grazing grounds have hampered the sheep production system. The biggest challenge facing the sheep industry today is figuring out how to address the nutritional issues facing the 65.06 million sheep that now exist. For this it is obligatory to develop the community lands for providing sufficient top feed through plantation of suitable fodder trees, bushes, shrubs, grasses and legumes (Meena *et al*., 2005). Pasture land management involves a set of technical and social interventions. The important technical interventions are identification and introduction of suitable grass and legume species, using suitable establishment techniques, fertilization of the pasture lands, regulating the grazing pressure and using an optimum stocking rate, use of rotational grazing system if feasible and increasing period the grazing period through introduction of top feed tree species. Research and development efforts to track the spatial behavior of cattle have expanded quickly (Trotter *et al*., 2010). Spatial livestock monitoring applications aid in tracking mobility and grazing pressure for welfare and health monitoring. In order to address the severe fodder shortage, cultivable waste lands provided by watershed development programs can produce a respectable amount of fodder/ha/year for grazing purposes. These grazing pastures are home to native fodder plants, which include scant, short, thin grass.

Pasture/Rangeland Establishment: Establishing rangelands is typically done in regions with low to moderate rainfall, when the amount and caliber of natural pasture declines throughout the dry season. The soil, rainfall, and grazing management techniques used all affect how well species perform in rangeland establishment. The community grazing lands must be improved by implementing tried-and-true methods such as bush cleaning, resowing, grubbing unwanted weeds, burning, fencing, manuring, fertilization, mixed grass and legume seed, conserving soil and water, increasing the interval between grazing periods, preventing illicit grazing, limiting overstocking rates, and planting fodder trees on pasture land. There are certain proven technologies have been developed for the sheep farmers like creating awareness among the shepherds about pasture and rangeland development and establishment. People participation is essential for rehabilitation of old degradation community land. There is need to increase shepherd awareness about new grass and legumes species for re-sowing of grazing lands. The social mobilization is essential among shepherds for grazing land improvement. According to Mapiye *et al*. (2006), legumes' capacity to fix atmospheric nitrogen makes them essential for enhancing tropical grasslands. Fodder seeds such as Lucerne, oats, cowpeas, sorghum, clitoria, stylo, and bajra are in high demand. The sheep breeders were inspired to use better cultivation techniques by field demonstrations. Farmers have embraced programs for the development of feed and fodder supplies. To boost production and fodder availability all year long, demonstrations of the creation and preservation of grazing land and silvipasture systems were implemented on farmer and community holdings.



Sheep Breeding: By crossing Rambouillet sheep with native sheep breeds such Chokla, Malpura, and Jaiselmeri, a beautiful wool sheep breed was created in 1962. Rambouillet was crossed with native breeds to create half-breds. To create ¾ Rambouillet, half-bred products were crossed with Rambouillet rams. Chokla and Naliewes were crossed with Rambouillet and Russian Merino in 1971. In 1982, the two programs' ¾ crosses were combined and given the name Bharat Merino. In order to boost the body weight and milk output of native Deccani sheep, Awassi sheep were imported from Israel and raised in southern Indian states including Andhra Pradesh, Maharashtra, and Karnataka. The Awassi breed of sheep is raised for both milk and meat, and in 238 days, it generated about 475 kg of milk with a fat content of 7-9%. Garole sheep improved the genetics of native sheep, such as Deccani and Nellore.

Milking parlour and related technologies: Control of the sheep milk parameters and identification of subclinical mastitis. Somatic cell count for identification of subclinical mastitis can be conducted in the milking parlour by using measurements of electric conductivity or by optic sensor evaluation of IR light scatter (Abdelgawad *et al*., 2016). Spectrophotometry and light scatter measurements can also be used for assessment of milk quality traits such as acidity and coagulation patterns. The introduction of automatic vacuum shut off systems to dairy sheep production aims to reduce the physical strain of the milking process, reduce the risk of over milking and reduce labour requirements. The system operates both based on time limitations (2-3 min activity) and flow measurement when it drops under 100 and 250 g min^{-1}. Precision feeding can also be achieved in the parlour itself by dedi cated single animal feeders that are able to provide a measured amount for the single sheep in the milking station.

Sheep Health Management: Develop worms-resistance breeds of sheep as Deccani and Bannur and they were crosses with galore rams were also evaluated under field condition. The lambs of Deccani sires and dams have the achievable higher growth rate; lambs of Garole sires were found more resistant to blood-sucking round worm (*Haemonchus contortus*). Sheep health services were provided to sheep breeders at their doorstep. Sheep were regularly treated for different ailments, vaccination against Enterotoxaemia, sheep pox and drenching against control of internal parasites loads were under taken in farmers flocks in order to reduce the morbidity and mortality.

Flock management software: There are currently a number of commercially available flock management software packages on the market. The main features include breeding lines, yield tracking, flock registry, and decision-making tools that allow farmers to compare individual animals with flock averages and trends. For instance, products like Sheep Tracker, Sum It, Flock Filer, and Farm plan (links accessible at the web reference section) combine information from multiple sources to track individual animals and their genetic makeup as well as present an overall picture of flock dynamics. Even though farmers are aware of the potential advantages of using such software, their interest in it is still quite low.

Wool Utilization and Marketing: Because they are unaware of better instruments for this task, the shepherds continue to shear wool using the old-fashioned methods. Prior to the start of this initiative, farmers sold their wool on a head basis; however, however, the majority of farmers shave their sheep and sell the wool in the Caribbean. Shepherds urgently need to be made aware of the proper use and marketing of wool. At the beginning of this initiative in the early 1960s and 1970s, between 60 and 70 percent of shepherds sold their wool after shearing it for 20 percent. As a result, their margin was Rs. 15

kg^{-1} of wool higher than it was on a head basis. After value addition in wool, the weavers' net income increased by 10-25% as a result of their adoption of the enhanced scheme. The farmers were trained about sheep wool blended with various vegetable, animal and synthetic fibres, spun into yarns in woolen and worsted systems and furnishing fabrics. In order to add value, the fabrics were dyed and polished. Throughout the various phases of their preparation, these materials were evaluated. The fibers are spun into yarns in woolen and woven systems, combined with different kinds of vegetable, animal, and synthetic fibers, and then transformed into a variety of goods like blankets, shawls, and upholstery materials.

Conclusion

Numerous solutions are available that are specifically designed for large-scale sheep farming, while new technologies are always evolving. The primary goals of these technologies are improved single animal production performance, lower labor expenses, and supplemental feeding. Nevertheless, the broad sheep farming industry, which is impacted by regional and international markets, internal cultural dynamics, and governmental regulations, does not always support the adoption of novel products. The main barriers to the broader adoption of novel technologies appear to be farmers' financial stability, their confidence in new technologies, and their receptivity to new concepts.

References

Abdelgawad, A. R., Rovai, M., Caja, G., Leitner, G. and Castillo, M. (2016). Evaluating coagulation properties of milk from dairy sheep with subclinical intramammary infection using near infrared light scatter. A preliminary study. *Journal of Food Engineering*, 168: 180-190.

Birthal, P. S., Deoghare, P. R. and Riyazuddin, S. K. (2003). Development of small ruminant sector in India. Project report submitted to Indian Council of Agricultural Research (ICAR), New Delhi, India.

Mapiye, C., Mupangwa, J. F., Mugabe, P. H., Chikumba, N., Poshiwa, X. and Foti, R. (2006). A review of forage legume research for rangeland improvement in Zimbabwe. *Tropical Grasslands*, 40(3): 145.

Suresh, S., Gupta, D. C. and Mann, J. S. (2010). Degradation of common pastures: an economics perspective of its impact on livestock farming and coping strategies. *Agricultural Economics Research Review*, 23(1): 47-56.

Tewari, V. P. and Arya, R. (2004). Degradation of arid rangelands in Thar Desert, India: A review. *Arid Land Research and Management*, 19(1): 1-12.

Trotter, M. G., Lamb, D. W., Hinch, G. N. and Guppy, C. N. (2010). Global navigation satellite system livestock tracking: system development and data interpretation. *Animal Production Science*, 50(6): 616-623.

Vermicompost and its Derivatives against Phytopathogenic Fungi

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Introduction

The world's population is expanding quickly, particularly in developing nations. To keep up with the demands of a growing human population, global agricultural production must double by 2050, but current projections fall short of this requirement (Ray *et al*., 2013). Plant diseases, weeds, and insects reduce crop productivity by 36% globally; diseases alone have been shown to reduce crop yield by 14%. On the other hand, the application of chemicals against such diseases mostly gives good results. However, the misuse of these inorganic substances has been an issue of public concern as they have destroyed the natural fertility of soil, killed beneficial soil organisms, reduced the natural resistance ability in crops, and also led to environmental pollution. According to many different groups of researchers, some pesticides are detrimental to other beneficial species even at recommended dosages, and when they are sprayed, some of them may stay on the agricultural area while others may end up in the nearby water, air, or soil. Vermicompost, a natural substance obtained after decomposition of organic materials by the activities of earthworms, contribute to valuable bioavailable nutrients and use complete microbes to boost soil fertility. Vermicompost application in agriculture has led to notable gains in crop health, production, and nutritional attributes; it also raises the mineral content of the soil, which improves the survival of beneficial bacteria. Additionally, because of the earthworms' coelomic fluid (CF) and other bioactive substances, vermi-compost has insecticidal and antifungal qualities, making it equally effective in suppressing illnesses and managing pests. Vermicompost and Vermi-compost tea, which have been deemed crucial in recent years for the control of numerous soil-borne phytopathogens, must be used as a safe and effective alternative against such diseases in order to address these issues. They are essential to organic farming because they improve soil fertility, nourish crops, and prevent diseases (Devi and Das, 2016). The application of compost and vermicompost as soil fertilizers helps in preserving, restoring soil fertility as well as enhancing soil biodiversity by substantially improving microbial biomass. Their application also plays a significant role towards sustainability in the agriculture production (De corato, 2020). The occurrence of a broad variety of antagonistic microbes in vermicast ensures the effici-

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ent bio control of soil borne phyto-pathogenic fungi.

Protective Mechanisms of Earthworm against Diseases

The drilosphere, or soil that contains earthworm secretions, burrows, and casts, is home to a variety of decomposer bacteria that aid earthworms in breaking down organic compounds that come from plants and animals. In order to shield the worms from harmful germs, these decomposer bacteria also form symbiotic connections with them in the stomach and drilosphere. Because of the bioactive substances included in their CF, mucus, and other epidermal secretions, earthworms may also defend themselves against harmful microorganisms. Humoral and cellular immunological responses are two of earthworm defense systems. Earthworms' cellular immune system consists of chloragocytes, eleocytes, coelomocytes, granulocytes, natural killer (NK) cells, and natural killer-like (NK-like) cells (Mehta *et al*., 2014).

Vermicompost: Antifungal Efficiency

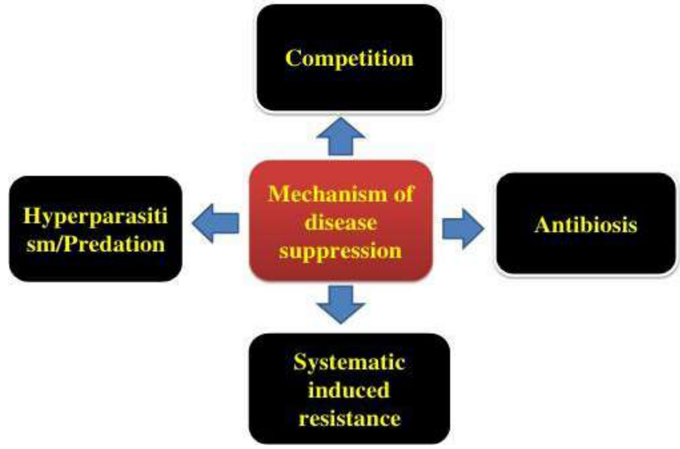
In plants, fungal infections are typically linked to significant morbidity and mortality. Drug-resistant microorganisms and detrimental consequences on environmental health have resulted from the widespread usage of antifungal drugs. Vermicomposting has been shown to have a disease-suppressive effect, which makes it a superior substitute for chemical fungicides. Vermicompost-associated earthworm secretions, such as Lumbricin-PG from earthworm skin secretions, have antifungal properties that can shield plants against fungal diseases. Vermicompost's antifungal properties are ascribed to decomposer bacteria forming a symbiotic relationship with earthworms. You *et al*. (2019) demonstrated that ergosterol peroxide is a bioactive metabolite derived from powdered bamboo vermicompost that considerably suppresses *R. solani* mycelium growth. This bioactive compound is secreted by vermicomposting bacteria using bamboo as a resource. Chaoui *et al*. (2002) confirmed that diseases caused by *Rhizoctonia* in radishes and Pythium in cucumbers significantly decreased in greenhouse and indicated that it was due to the presence of biocontrol agent *Trichoderma* spp. in the vermicompost. Significant levels of suppression on the disease incidence caused by *Verticillium* in strawberries and Phomopsis and *Sphaerotheca fulginae* in grapes were also achieved by them under field conditions. They also reported that vermicompost lost its suppressive ability when it was sterilized, thus persuasively suggesting that the mechanism for suppressing disease is biological. Sahni *et al*. (2008) compared the suppressive effects of two unconventional chemicals, oxalic acid and zinc sulfate (ZnS04), as well as the bioagent *Pseudomonas syringae* and vermicompost, against *Sclerotium rolfsii*, which causes collar rot disease in chickpeas. Vermicompost amendments were found to significantly lower chickpea mortality when compared to the control. However, pre-inoculation with chemicals had a more effective suppressive effect on *S. rolfsii*. They discovered that the combination of chemicals and vermicompost was responsible for the strengthening and stimulation of defense mechanisms, such as systemic acquired resistance, in chickpea plants.

Vermiwash as Antifungal Agent

Fusarium graminearum, a well-known pathogenic fungus, has a significant impact on plant roots, reducing the quality and yield of wheat production by 20%. In crops affected by fungal infection, the application of vermiwash (a liquid extract of vermicompost rich in earthworm mucus and bioactive compounds) has been shown to minimize the pathogenic effect, reducing mycelial growth. It has been shown that *Eisenia fetida* extract significantly inhibits the growth of *F. graminearum*. Applying earthworm mucus to agricultural land reduces fungal infections by 26% and prevents the proliferation of disease-causing bacteria in the soil. However, vermiwash only reduced mycelium growth by 16%, suggesting that its effectiveness was significantly lower than that of the applied mucus. *Bacillus* species are known to establish mutualistic relationships with earthworms and produce bioactive compounds against fungal pathogens in vermicom-post. The combined application of Bacillus amyloliquefaciens and dipotassium phosphate (DPP) was used as a decoction to suppress the mycelial growth of *Alternaria solani*.

Mechanisms of Plant Disease Suppression by Vermicompost Products

Overall research on applications of vermi-compost products, either solid or liquefied, to control plant diseases has shown that suppression effect has a biological nature rather than chemical, similar to that of compost products.

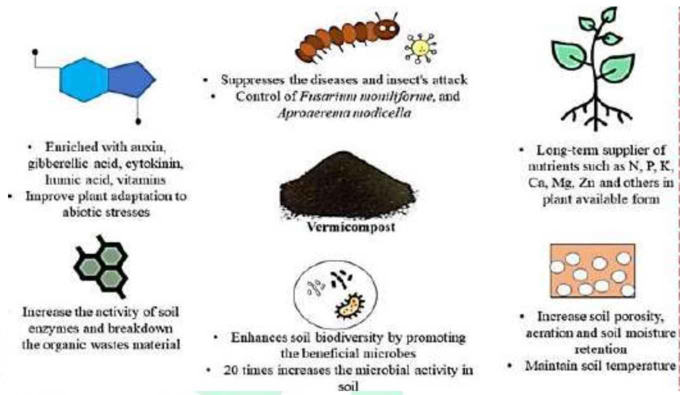


An overwhelming body of evidence in the literature indicated that microbial communities, stimulated by conventional aerobic compost amendments, are responsible for disease suppression. Proposed disease suppression mechan-isms for control of plant pathogens via application of conventional composts are defined within two types as general and specific suppression mechanisms that include microbial antagonism, nutrient release, induced host resistance, and abiotic inhibi tory factors of disease suppression. One of these disease suppression mechanisms termed as "general supper-ssion" has been defined by nutrient competition, antibiosis, in which beneficial organisms secrete antibiotics that directly inhibit the pathogen, hyperparasitism/direct parasitism (one organism feeding on another), and possibly induced systemic plant resistance. That suppression mechanism has been described based on the concept that a high biodiversity of microbial populations act as bio control agents that creates conditions such as fungistatis unfavorable for plant pathogens to develop.

Suppression of nutrient-depended plant pathogens such as Pythium and *Phytopthora* was explained by general suppression mechanism. Competition is the most commonly defined factor within the context of general disease suppression mechanism in use of composts, produced by either aerobic composting or vermicomposting. Therefore, the level of disease suppressiveness is typically related to the level of total microbiological activity (active microbial biomass) in a soil. The larger the soil's active microbial biomass, the greater the soil's capacity to use carbon, nutrients, and energy, lowering the nutrient availability to pathogens. In other words, when most soil nutrients are tied up in microbial bodies, the competition for readily available mineral nutrients gets a higher level. Competition is the most commonly defined factor within the context of general disease suppression mechanism in use of composts, produced by either aerobic composting or vermicomposting. Therefore, the level of disease suppressiveness is typically related to the level of total microbiological activity (active microbial biomass) in a soil. The larger the soil's active microbial biomass, the greater the soil's capacity to use carbon, nutrients, and energy, lowering the nutrient availability to pathogens. In other words, when most soil nutrients are tied up in microbial bodies, the competition for readily available mineral nutrients gets a higher level.

Conclusion

Since the 1970s, alternative plant disease and waste management strategies have been extensively researched and investigated in conjunction with growing concerns about the negative side effects of agrochemicals and inappropriate organic waste management approaches. As a new industrial sector, vermicompost offers many options for managing biodegradable organic waste and producing food without the use of agrochemicals.



Vermicomposting has enormous potential for using a variety of feedstocks of on- and off-farm wastes, such as those produced in industrial, municipal, food processing, agriculture, wood processing, and sewage treatment. Vermicompost and its derivatives, such as vermiwash, along with associated decomposer bacteria, act against fungal pathogens. The antifungal efficacy of vermicompost may be associated with bioactive compounds present in the CF, mucus, skin secretion of earthworms and metabolites secreted by decomposer bacteria.

References

Sahni, S., Sarma, B. K. and Singh, K. P. (2008). Management of *Sclerotium rolfsii* with integration of non-conventional chemicals, vermicompost and *Pseudomonas syringae*. *World Journal of Microbiology and Biotechnology*, 24(4): 517-522.

Chaoui, H., Edwards, C. A., Brickner, A., Lee, S. S. and Arancon, N. Q. (2002). Suppression of the plant diseases, Pythium (damping-off), Rhizoctonia (root rot) and Verticillium (wilt) by vermicomposts. In *Brighton Crop Protection Conference Pests and Diseases* (Vol. 2, pp. 711-716).

De Corato, U. (2020). Disease-suppressive compost enhances natural soil suppressiveness against soil-borne plant pathogens: A critical review. *Rhizosphere*, 13: 100192.

Devi, T. H. and Das, D. (2016). Effect of organic amendments on root-knot nematode (*Meloidogyne incognita*) in cucumber. *Pest Management in Horticultural Ecosystems*, 22(2): 176-181.

Mehta, C. M., Palni, U., Franke-Whittle, I. H. and Sharma, A. K. (2014). Compost: its role, mechanism and impact on reducing soil-borne plant diseases. *Waste Management*, 34(3): 607-622.

Ray, D. K., Mueller, N. D., West, P. C. and Foley, J. A. (2013). Yield trends are insufficient to double global crop production by 2050. *PloS one*, 8(6): e66428.

You, X., Wakana, D., Ishikawa, K., Hosoe, T. and Tojo, M. (2019). Antifungal activity of compounds isolated from bamboo vermi-compost against *Rhizoctonia solani* AG1-IB. *Advances in Microbiology*, 9(12): 957.

Role of AI and Machine Learning in Agriculture and Allied Science

Namitha Elza Tom, Rajesh Kanwar and Mohd Anas

Introduction

Any economy's foundation for sustainability is agriculture. Although it varies per country, it is essential to long-term economic growth and structural transformation. Agriculture used to be restricted to the production of crops and food. However, over the past 20 years, it has changed to include the production, distribution, marketing, and processing of agricultural and livestock goods. Nowadays, agriculture provides the majority of people's income, boosts GDP, contributes to national trade, lowers unemployment, supplies raw materials for other industries' production, and generally advances the economy. The pressure on the agriculture sector will increase with the con tinuing expansion of the human population and so agri-technology and precision farming have gained much importance in today's world. This are also termed as digital agriculture which means the use of hi tech computer systems to calculate different parameters such as weed detection, crop prediction, yield detection, crop quality and many more machine learning techniques (Liakos *et al.*, 2018). The development of computer systems that can carry out tasks that traditionally require human intelligence is called artificial intelligence (AI). Artificial intelligence comprises several subfields and approaches, like machine learning, linguistic processing, computer vision, robotics, specialized systems and brain networks. Artificial Intelligence (AI) has been gradually introduced in agriculture over the past decade, with increasing adoption in recent years. In the early 2000s, the idea of precision agriculture which entails using technology to manage crops according to their specific sites came into being. Precision agriculture is a data-driven method that utilizes various instruments like sensors, drones, GPS guidance systems, and machine learning algorithms to analyse and address field variability. This strategy allows farmers to assess changes in crop health, soil composition, and moisture levels to make informed decisions tailored to specific sections of their farm (Linaza *et al.*, 2021). Precision agriculture aims to enhance global food production by utiliz ing farm inputs such as fertilizer, pesticides, and water efficiently through real-time data collection and analysis to improve yield, efficiency, and environmental sustainability. The progress in many agricultural areas has been sped up by the remarkable development of machine learning (ML)

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and Artificial Intel ligence (AI) vision in agriculture. Initially employed for crop monitoring and production prediction, machine learning techniques have since broadened to encompass a variety of agricultural applica tions. The applications utilize extensive datasets for predictive analytics and decision-making. AI vision systems have reinvented pest identification, disease detection, and crop analysis, allowing for precise and prompt actions. Autonomous vehicles and drones are already capable of doing intricate tasks such as planting, spraying, and harvesting in fields due to the combination of machine learning algorithms with artificial intelligence vision technology (Shaikh *et al*., 2022).

Importance of technological advancements in agriculture

Throughout history, technological developments have been crucial to the growth and expansion of agriculture. Agriculture has seen tremendous changes, from the use of basic tools like sickles and plows to the use of contemporary machinery and equipment. Recent developments in AI, data analytics, and information technology have ushered in a new era of agricultural innovation. Technological developments in agriculture are significant in a number of ways:

Increased productivity: Technology has enabled farmers to increase their productivity by improving cultivation techniques, crop varieties, and animal breeds. Mechanization has reduced manual labour, increased efficiency, and allowed for larger scale operations.

Efficient resource management: Technology has facilitated efficient management of key resources such as water and fertilizers. Irrigation systems can be automated based on real-time data, minimizing water usage. Similarly, smart fertilization techniques can deliver nutrients precisely where and when they are needed, minimizing environmental impact.

Precision agriculture: Technology has enabled precision agriculture, which involves the use of sensors, drones, and satellite imagery to monitor and manage crops with precision. Farmers can collect data on soil moisture, nutrient levels, and crop health to optimize resource allocation, reduce waste, and increase yields.

Disease and pest management: AI and ML techniques can analyse large volumes of data to detect and predict disease outbreaks and pest infestations. Early detection allows farmers to take proactive measures, reducing crop losses and the need for excessive pesticide use.

Role of Artificial Intelligence (AI) and Machine learning (ML) in Agriculture

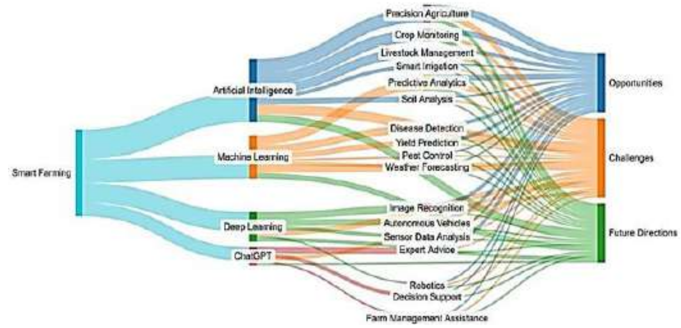
Agricultural robotics: AI-powered robots can perform tasks such as planting, harvesting, weeding, and monitoring crop health. These robots can navigate fields autonomously, collect data, and execute actions based on predefined algorithms. This reduces labour costs, increases efficiency, and enables round-the-clock monitoring.

Crop and soil monitoring: AI and ML algorithms can analyse satellite imagery, drone data, and sensor inputs to monitor crop growth, identify nutrient deficiencies, detect diseases, and predict yield potential. This information enables farmers to make data driven decisions and take proactive measures to optimize crop performance. The effects of different management techniques, including crop rotation or the use of specific fertilizers, on soil health over time can be predicted using machine learning algorithms. Real-time data from soil-embedded sensors is included into soil monitoring services provided by AI-driven solutions like CropX. By giving farmers practical guidance on when and how much to fertilize, irrigate, or treat their soil, these technologies improve crop yields and promote sustainable farming methods.

Precision farming: Precision farming, or precision agriculture, is a major AI-driven innovation in the agricultural sector (Singh and Kaur, 2022). AI algorithms can be used by farmers to collect and analyze data in order to optimize crop production procedures. Drones, IoT (Internet of Things) sensors, and satellite imagery provide real-time data on crop health, soil conditions, and weather patterns. By analyzing this data, AI systems help farmers make better use of their resources by offering guidance on fertilizer, irrigation, and insect control. In order to predict agricultural output, soil requirements, and potential problems like disease outbreaks, machine learning (ML) systems analyze vast amounts of data. AI and ML techniques can create precise field maps, guiding farmers in optimizing inputs such as irrigation, fertilization, and pesticide application. By tailoring these practices to specific crop needs and growth patterns, farmers can maximize resource efficiency and minimize environmental impact.

Pest and Disease Detection: Artificial intelligence is essential for the detection and management of pests and diseases in agriculture (Linaza *et al*., 2021). Timely identification is essential to avert extensive infestations that may result in considerable production reduction. AI-driven technologies such as image identification and machine learning can detect pests and diseases from crop photos, enabling farmers to implement preventive measures prior to the proliferation of infestations. Smartphone applications utilizing AI models, such as Plantix and PlantVillage Nuru, allow farmers to input images of distressed plants and obtain immediate diagnosis and treatment suggestions. Furthermore, AI-enhanced drone technology may identify pests and illnesses in extensive agricultural areas by acquiring high-resolution images and analyzing them with machine learning models designed to detect indicators of crop distress. These AI-operated drones can traverse extensive regions more rapidly and effectively than manual reconnaissance, enhancing early detection and response times. Conventional techniques for pest and disease identification are frequently laborious and may lack sufficient accuracy. Machine learning models, particularly those employing deep learning methodologies such as Convolutional Neural Networks (CNNs) and Recurrent Neural Networks (RNNs), have proven pivotal in the automated detection of illnesses and pests via image-based systems. Recent research emphasizes the development of deep learning models capable of analyzing photos of leaves, stems, or fruits to identify indicators of diseases such as leaf spots, rusts, and mildews. These models are trained on extensive datasets of plant photos to identify specific disease symptoms that may be imperceptible to the naked eye.

Predictive analytics: In order to forecast weather patterns, market trends, and crop performance, AI and ML models may analyze both historical and current data. These data can help farmers make well-informed decisions on crop diversification, market timing and planting timetables. Artificial intelligence is revolutionizing the agriculture insurance sector by facilitating the creation of more precise and equitable insurance offerings. AI-driven predictive analytics enables insurers to evaluate risks with more accuracy by examining extensive data on meteorological trends, soil quality, and agricultural health. AI algorithms can forecast the probability of unfavorable events, including droughts, floods, or insect infestations, enabling insurers to provide more customized coverage for farmers.



Livestock management: AI and ML techniques can be used to monitor animal health, behaviour, and productivity. Sensors and wearable devices can collect data on parameters such as temperature, heart rate, and milk production, enabling early disease detection and timely intervention. Machine learning and deep learning extend beyond crop production; they are also significantly enhancing animal management. AI-driven systems may oversee the health and welfare of animals, monitor their travels, and evaluate their behavioral patterns to identify any indications of illness or distress. Sensors affixed to animals can gather data on body temperature, heart rate, and activity levels. Machine learning models can subsequently examine this data to forecast disease outbreaks or identify animals in need of urgent care. Additionally, deep learning models utilizing video feeds may observe cattle behavior and detect anomalies, such as diminished activity or irregular eating patterns, which may signify health concerns.

Agricultural drones: Drones equipped with AI and ML capabilities can capture high resolution imagery and perform aerial surveys. This data can be used for crop monitoring, mapping, and identifying areas of concern, providing farmers with actionable insights.

AI in Biodiversity Conservation and Sustainable Agriculture

Artificial intelligence is assuming a progressively significant role in advancing biodiversity and sustainable agricultural methods. Through the analysis of data from sensors, satellites, and environmental monitoring systems, AI models can assist farmers in implementing more sustainable practices that safeguard ecosystems and preserve biodiversity. AI can aid in identifying the most advantageous locations for crops and habitats to reduce environmental impact and promote wildlife conservation. AI-driven decision-making tools assist farmers in implementing strategies like agroforestry, cover cropping, and no-till farming, which mitigate soil erosion, improve soil fertility, and create habitats for beneficial insects and animals.

Future Directions and Research Opportunities of AI & ML

The creation of complex decision support systems (DSS) is a key topic of AI research in smart farming. By analyzing large databases, these technologies help farmers make well-informed decisions about planting, irrigation, pest control, and harvesting. In order to enable dynamic decision-making in response to constantly changing field conditions, future research may focus on integrating real-time sensor data with AI-driven analytics. AI systems are able to predict the location and timing of insect outbreaks, which enables farmers to avoid the use of hazardous chemicals and administer treatments more effectively. Crop production prediction is one of the most important applications of machine learning in agriculture, where it has shown notable effectiveness in predictive analytics. In order to predict future outcomes with a high degree of accuracy, machine learning models may examine a large amount of historical data, such as weather patterns, soil properties, and previous crop yields. However, the challenge lies in the diversity of agricultural data, which is often fragmented and unstructured. To maximize the use of this data, future studies can look at the use of federated learning techniques and unsupervised learning algorithms. The optimization of multi-crop yields is a significant potential.

Conclusion

The integration of Artificial Intelligence (AI) and Machine Learning (ML) technologies in agriculture has emerged as a transformative force, revolutionizing the way farming and related practices are conducted. The advancements in AI and ML have enabled farmers and agricultural stakeholders to make more informed decisions, optimize resource allocation, increase productivity, and promote sustainable practices. One of the key benefits of AI and ML in agriculture is the ability to gather, process, and analyses vast amounts of data from various sources, such as weather patterns, soil conditions, crop health, and market trends. This data driven approach empowers farmers to make real-time decisions and take proactive measures to mitigate risks, maximize yields and minimize environmental impact.

References

Liakos, K. G., Busato, P., Moshou, D., Pearson, S. and Bochtis, D. (2018). Machine learning in agriculture: A review. *Sensors*, 18(8): 2674.

Linaza, M. T., Posada, J., Bund, J., Eisert, P., Quartulli, M., Döllner, J., ... and Lucat, L. (2021). Data-driven artificial intelligence applications for sustainable precision agriculture. *Agronomy*, 11(6): 1227.

Shaikh, T. A., Rasool, T. and Lone, F. R. (2022). Towards leveraging the role of machine learning and artificial intelligence in precision agriculture and smart farming. *Computers and Electronics in Agriculture*, 198: 107119.

Singh, P. and Kaur, A. (2022). A systematic review of artificial intelligence in agriculture. *Deep Learning for Sustainable Agriculture*, 57-80.

Linaza, M. T., Posada, J., Bund, J., Eisert, P., Quartulli, M., Döllner, J., ... and Lucat, L. (2021). Data-driven artificial intelligence applications for sustainable precision agriculture. *Agronomy*, 11(6): 1227.

Nematodes as Biological Indicators

Naresh Kumar Nayak, Pallavi Palande and Ramachandra Naik M.

Introduction

As the human population increases, so does the demand for resources, especially food. To meet the increasing demand for food, inappropriate soil management such as intensive use of chemical fertilizers and pesticides poses a hazard to soil health, and modern agriculture must be made sustainable. Healthy soils are essential in sustainable agricultural development and the use of indicators to assess soil health is increasingly popular. Soil health is "the continued capacity of soil to function as a vital living system, within ecosystem and land-use boundaries, to sustain biological productivity, maintain the quality of air and water environments, and promote plant, animal, and human health (Doran *et al*., 1996). Various environmental problems like global climate change, stratospheric ozone depletion, habitat destruction, and species extinction have threatened the world. Environmental scientists are trying to adequately assess ecological status and to detect trends and changes in environmental condition. Bioindication is scientific analysis of ecological information to make interferences about the quality of the environment at that area.

Therefore indicator is used to describe and evaluate ecological conditions and trends, to anticipate emerging problems and address national and international monitoring for policy, legislation and administrative purpose. The use of Bioindicators is an innovative approach for assessing various types of environmental mismanagement, including pollution, high input farming, inappropriate disposal of wastes, contamination, etc. This approach uses biological organisms and biodiversity as tools to assess ongoing situations in the environment. In terms of biology, soil ecosystems support a variety of mesofauna (arthropods and nematodes), microfauna (protozoa), and microorganisms (fungi, bacteria, and algae). The type and condition of the environment are reflected in the abundance of organisms. Diversity, biological richness, and the abundance of plants and animals have all been debated by ecologists as indicators of environmental quality. Any indicator need to adapt to modifications in soil conditions brought about by land-management techniques and represent the composition and operation of ecological processes. Selecting a minimum set of indicators that are simple, easy to evaluate, utilize the greatest amount

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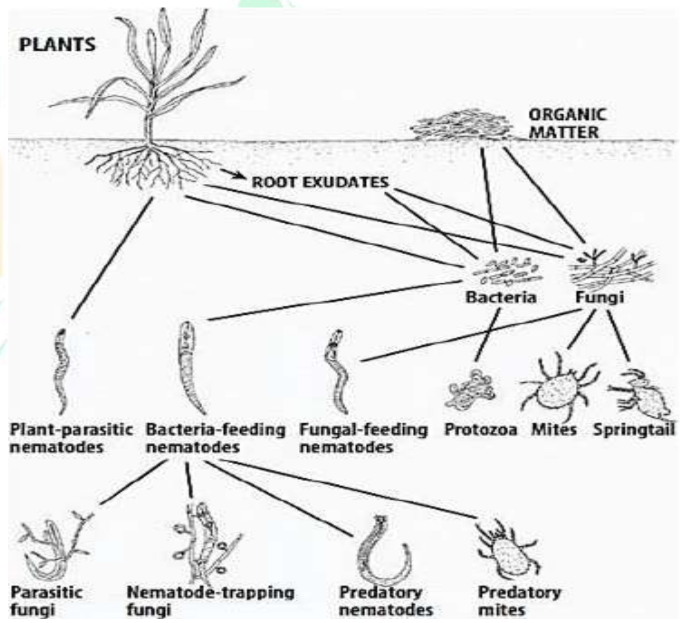
of habitat, are highly sensitive to changes in the environment, to soil and climate management, and can be measured using quantitative and/or qualitative methods is crucial (Saviozzi *et al*., 2001). Three kinds of mesofauna-nematodes, collembolan, and mites have been proposed for use as biological indicators. Nematodes have received the most evaluations for their potential as indicators among these three groupings. Nematodes are phylum Nematoda members of the animal kingdom. They are a very diverse collection of animals on Earth and are typically minute organisms (Ekschmitt *et al*., 2001).

Nematodes as Indicator Species

Nematodes possess several attributes that make them useful ecological indicators. Soil nematodes can be placed into at least five functional or trophic groups, and they occupy a central position in the detritus food web. A small fraction of soil fauna depends directly on primary producers, feeding on plant roots and their exudates. The subgroups of these organisms that form parasitic relationships with plants and their roots are the best known of soil organisms because of the damage they cause to agricultural crops such as decreasing plant production, disrupting plant nutrient and water transfer, and decreasing fruit and tuber quality and size. Nematode constitutes nearly 90% of all Metazoa in number (Hugot *et al*., 2001). Nematodes are found in almost every kind of habitat i.e. terrestrial, rivers, lakes, marine, freshwater, ice land etc. Nematodes are representing a central position in the soil food web. Nematodes occur in all soil and aquatic systems: in acidified forests soil, in heavily polluted soil, on heavy clay, in deep sea sediments, in rotting plant material, in compost and in any habitat in which organic material is decomposed. They are susceptible to variations in their activity and distribution as well as environmental influences. Nematodes are used as markers in the biologists are currently very interested in environmental status detection. Since the number of possible environ-mental contaminants rises every year, mostly due to an inability to predict toxicity, such an indicator is required.



The Importance of Nematodes as Bioindicators

Nematodes have multiple traits that make them useful ecological indicators:

Ubiquity and abundance: Nematodes are ubiqu-itous and abundant in soil environments, making them readily available for sampling throughout the year in most ecosystems. This characteristic makes them suitable for both local and large-scale regional monitoring efforts.

Ease of sampling: The relatively small size and high abundance of nematodes simplify sampling and extraction processes, resulting in lower costs compared to other soil fauna.

Functional diversity: Soil nematodes encompass a variety of functional or trophic groups, exhibiting different life history characteristics, such as colonizers and persisters.

Morphological differences: The structure and function of nematodes are strongly correlated. This allows for easy separation of trophic or functional groups based on morphological structures associated with their various feeding modes.

Sensitivity to environmental disturbances: The susceptibility of nematodes to direct and indirect biological, chemical, and physical perturbations in soil ecosystems varies. While some species develop resistant stages like cysts or anhydrobiotic stages that allow them to endure adverse environments, others that do not have such stages are more vulnerable to environmental disruptions.

Biomarker potential: Nematodes have heat shock proteins, which are activated when exposed to stressors such as heat, metal ions, or organic toxins. These proteins may serve as biomarkers for Eco-toxicological assessment of soils.

Influence on soil function: The composition of the nematode community has an impact on soil function that is related to agricultural productivity and sustainability. Nematode maturity indices reflect successional changes in nematode communities in response to anthropogenic disturbances.

Bioassay Techniques for Bioindicator

Microcosms: A controlled, reproducible laboratory system that aims to replicate the conditions (i.e., component interactions and processes) in a section of the real world is called a microcosm. Depending on the knowledge and presumptions regarding the environment simulated and the experiment being conducted, the researcher can allow the system to be open, semi-closed, or closed to fluxes of air, water, and biota to environmental conditions (light, temperature, humidity), as well as to the content of soil or other compounds.

Pollution-Induced Community Tolerance (PICT) : Toxic chemicals in the environment exert selective pressure on biota, eliminating sensitive organisms. The restructured community will be more tolerant to the toxicant than the original community. PICT may be used to detect minor changes occurring in contaminated ecosystem, estimate the size of the influenced area and find the (group of) compounds(s) causing the impact. This is achieved by combining ecological and physiological approach. PICT can be used to discriminate between primary and secondary effects of the toxicant. Finally, if co-tolerance patterns are identified, these will give an indication of the physiological mode of action of the toxicant and also a rough idea of possible tolerance mechanisms.

Indices: Nematode-based environmental change has been described using a range of graphical and statistical techniques or indices. Nematode faunal analysis is the source of ecological indices, which offer valuable bioindicators for soil environmental disturbance and the state of the soil food web. Together with its ecological indices, nematode fauna composition has become a valuable indicator of environmental conditions, soil ecosystem function, and benthic ecosystems. Mature index, diversity index, similarity index, key species, N/C ratio, physiological index, Plant parasite index (PPI), Sigma MI (which includes all soil nematodes), diversity index (H"), and Wasilewska index (WI) are among the nematodes that have been discovered to correlate with soil pollutant concentrations.

Conclusion

As the most common and plentiful multicellular organisms in soil, nematodes are essential to soil food webs and have a significant impact on vital ecological processes including plant development and nitrogen cycling. Thus, there is substantial informational value in the structure of soil nematode colonies. Nematodes are useful ecological indicators for evaluating soil health and tracking ecosystem perturbations because of their many characteristics. Nematode-based biotic indicators have shown promise in assessing soil health in a variety of geographical locations, in both natural and managed ecosystems. Utilizing nematodes as bioindicators integrates both biotic and abiotic factors, offering insights into the function and structure of soil ecosystems. In India, the predominant focus of nematology research lies in managing plant parasitic nematodes, which contribute to crop losses.

References

Doran, J. W., Sarrantonio, M. and Liebig, M. A. (1996). Soil health and sustainability. *Advances in Agronomy*, 56: 2-55.

Ekschmitt, K., Bakonyi, G., Bongers, M., Bongers, T., Boström, S., Dogan, H., ... and Wolters, V. (2001). Nematode community structure as indicator of soil functioning in European grassland soils. *European Journal of Soil Biology*, 37(4): 263-268.

Hugot, J. P., Baujard, P. and Morand, S. (2001). Biodiversity in helminths and nematodes as a field of study: an overview. *Nematology*, 3(3): 199-208.

Saviozzi, A., Levi-Minzi, R., Cardelli, R. and Riffaldi, R. (2001). A comparison of soil quality in adjacent cultivated, forest and native grassland soils. *Plant and Soil*, 233(2): 251-259.

Next Generation Seed Priming

Niti Kushwaha, A. Bhargavi and Deeksha Sharma

Introduction

Environmental pollution and abiotic stresses are major global problems affecting seed germination, emergence and vigour of seedling and ultimately crop yield. These unfavorable conditions have a severe impact in many agricultural areas especially arid and semi-arid lands (Kamithi *et al*., 2016). Abiotic stresses affect the plant growth and crop yield by delaying the start of germination and reducing its rate of growth. Seed is a growth driver of agriculture and efficacy of all other agricultural inputs, *viz*., irrigation, fertilizers and plant protectants, and human labour revolves around the use of quality seed. Seed is a tool for delivery of improved technologies and is a mirror for portrayal of inherent genetic potential of a variety/hybrid. Seed offers to integrate production, protection and quality enhancement technologies through a single entity, in a cost-effective way. Seed can play a pivotal role in achieving higher productivity; the use of quality seeds alone could increase productivity by 15-20 % which highlights the important role of seed in agriculture. India being an agricultural country urges the need of simple, effective and manageable technology to enhance establishment of crops under all environmental conditions. Different techniques can be used to enhance crop yield of which, seed priming is the simple and suitable technique to synchronise seed germination, increase emergence and establishment in the farm (Mirshekari, 2012). Seed priming treatment is done before sowing seeds, which involves hydration of seeds plentiful enough to enable metabolic events before germination to take place, although preventing radicle emergence to occur. Priming is the process of pre-treating seeds before planting those plants using traditional methods such as pre-soaking and coating. Alternative seed hydration methods (with or without aeration) are used in the pre-germination phase, and seeds are then re-dried to the usual moisture content of the regular handling process such as sowing, packaging, and preservation. Seed dormancy can be reduced by treating the seeds in salt solutions (halo-priming), water (hydro-conditioning), osmotic agents (osmo-priming), plant hormone solutions (hormonal priming), valuable microbe solutions (bio-priming), under a magnetic field (magneto-priming), a solution containing a solid carrier (matri-conditioning), and solutions containing nanoparticles (NPs) (nano-priming). This promotes a number of

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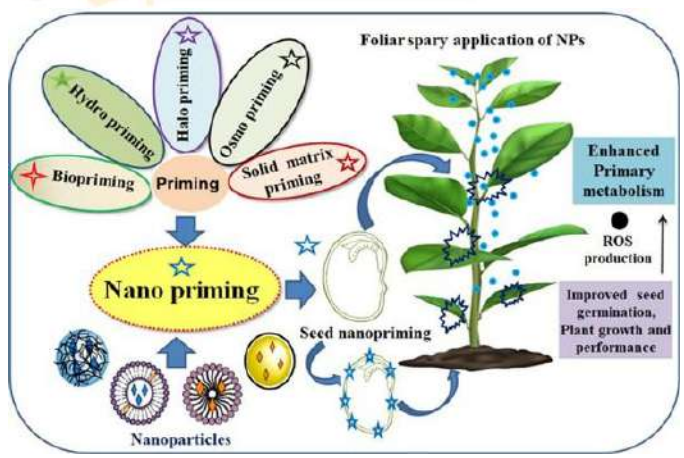
metabolic processes that enhance the germination and emergence of a number of seed types, especially ornamental species, small-seeded grasses, and vegetable seeds. Additionally, it undoes the negative consequences of seed degradation. Seed priming is regarded as a simple, low-risk, low-cost, and very successful method. Primed seeds have many benefits, including consistency and an earlier, faster appearance.

Climate Extremes and Germination Challenges

Drought Stress: Drought stress reduces the amount of water available in the soil, which restricts the absorption of water by roots and lowers the turgor of leaves. This, in turn, slows the emergence and establishment of seedlings (Blum, 2011). Lack of water reduces the mobilization of seed stores, inhibits enzymatic activity necessary for germination, and impairs cell proliferation. In extreme situations, metabolic halt brought on by desiccation of seed tissues delays germination even further. Additionally, drought promotes the buildup of abscisic acid (ABA), which inhibits germination signals. Because of these physiological and biochemical limitations, seeds experiencing water deprivation exhibit uneven and sluggish emergence.

Heat Stress: Elevated temperatures cause lipid fluidity to increase, which compromises membrane integrity and allows vital solutes to seep out. Heat stress damages proteins, lipids, and nucleic acids by accelerating the production of reactive oxygen species (ROS). During germination, this kind of oxidative stress prevents the activation of seed enzymes. Heat sensitive proteins, particularly those involved in respiration and reserve mobilization, are also denatured by prolonged exposure to heat. Heat shock proteins are used by plants as a defensive mechanism, but they are often inadequate to stop the quick cellular damage that occurs during seedling emergence.

Hypoxia and Flooding: The oxygen levels around the seed and root zone are reduced when flooding saturates the soil. Because aerobic respiration is hampered in such hypoxic environments, seeds must depend on less effective anaerobic routes to produce ATP. Cell division, elongation, and root penetration into the soil are all hampered by the lack of energy. Furthermore, harmful byproducts like lactic acid and ethanol build up and harm seed tissues. By increasing ethylene, hypoxia also throws off the hormonal balance and often prevents proper germination and seedling growth.



Stress from Salinity: Osmotic imbalance and ion toxicity from excess Na^+ and Cl^+ are the two hazards that seeds face while under salinity stress (Munns and Tester, 2008). Imbibition, the first stage of germination, is suppressed by high osmotic potential, which decreases water intake. In the meanwhile, vital nutrients like calcium and potassium are displaced as sodium and chloride ions build up in tissues. Enzymatic activity, photosynthesis, and general seedling vigor are all hampered by this imbalance. Salinity is one of the most complicated abiotic factors affecting seedling development because ion buildup over time results in oxidative stress and damages cellular organelles.

Increased CO_2: The respiration and metabolism of seeds are altered by elevated CO_2 levels. More CO_2 may stimulate seeds in some species to store more carbohydrates, which boosts germination and vigor. However, the effect is inconsistent; some studies suggest that unbalanced carbon to nitrogen ratios lead to unstable germination. Furthermore, the regulation of hormones, particularly gibberellins and ABA, which govern germination and dormancy, is altered by excessive CO_2. Over time, these modifications may modify how seedlings develop, sometimes increa-sing rapid early growth while decreasing stress tolerance.

Next Generation Seed Priming through Nano Priming

Examples of modern priming techniques include hydro-priming, osmo-priming, hormonal priming, nutri-priming, on-farm priming, and bio-priming that have demonstrated significant advantages for crops, such as higher crop yield and micronutrient concentrations in cereals, improved germination rates, germination energy, growth and development, and increased resistance to biotic and abiotic stress. Additionally, different priming agents should be tailored to the unique characteristics and potential of each crop species. For attaining practical agricultural yields, priming with nanoparticles (nano-priming) has been shown to be more promising than conventional priming techniques (Abbasi Khalaki *et al*., 2021). Nano-priming uses nanoparticles (NPs) with a size of less than 100 nm, and "priming" relates to the develop ment of stress tolerance under moderate and recurring stress. It has been reported that seed germination and seedling vigor are potentially induced in various crops upon nano-priming. Moreover, this may be one of the best methods to sort out the dormancy problems and increase the germination of seeds in forest species (upland boreal), which indicates that nano-priming can be useful for forest reclamation purposes.

Next-Generation Breeding and Nano-Priming Integration

The application of omics tools, particularly transcriptomics, genomics, proteomics, metabolon-mics and phenomics, signifies a revolutionary approach to recognizing plant resilience to biotic and abiotic challenges. This multi-omics paradigm enables researchers to examine the intricate relationships among many biochemical elements and their functions in stress responses, which brings about beneficial crop enhancement tactics (Varadharajan, *et al.* 2025).

Selection by Genomic (GS): Genomics examines an organism's entire DNA sequence. Under abiotic and biotic stress conditions, it helps locate quantitative trait loci (QTLs) responsible for stress tolerance. Modern tools like genome-wide association studies (GWAS) reveal genetic variations connected with beneficial traits, supporting marker-assisted breeding to create stress-resistant crop varieties (Roychowdhury *et al.*, 2023). Genomic selection (GS) uses markers distributed across the genome to more precisely predict complex traits, such as germination index. This improves selection efficiency and allows breeders to evaluate large populations without the high costs of extensive phenotyping.

Breeding by Epigenomics: It is possible to inherit stress memory via DNA methylation and histone changes, which enhances germination under repeated stress. These epigenetic fingerprints are further amplified by nano-priming, which confers a long-term adaptive benefit.

Editing the CRISPR/Cas genome: Seed stress tolerance is directly increased by using CRISPR/Cas to edit the genes for aquaporin, HSP, and LEA. With fewer yield trade-offs, these exact changes aid in the development of cultivars that can tolerate heat, salt, and drought.

Biotechnological and Omics Approaches

Proteomics: Proteins play a crucial role in managing stress responses, functioning as major regulators of cellular balance and physiological activities that contribute to the development of new stress-adaptive traits. Proteomics helps reveal changes in protein expression and identifies the pathways activated during abiotic stress (Ahmad *et al*., 2016). During nano-priming, proteomic analyses show elevated levels of proteins involved in osmotic adjustment and antioxidant defense (Rahman *et al*., 2016). These proteins act as an initial protective barrier by preserving cellular integrity and improving seedling survival under stressful conditions.

Transcriptomics: Transcriptional networks control how plants respond to biotic and abiotic stresses by adjusting gene activity through transcription factors and their interactions (Nakashima *et al.*, 2014). Numerous stress-responsive transcription factors and signaling cascades are activated by nano-priming. By activating genes related to water balance, anti-oxidation and growth control, this molecular reprogramming promotes early germination.

Metabolomics: Proline, soluble sugars, and phenolic substances are highlighted by metabolomic investigations as trustworthy indicators of nano-primed seeds. Osmotic stability, ROS scavenging, and general metabolic preparedness for stress tolerance are all enhanced by their buildup.

Phenomics: Automated seed imaging and growth analysis are two examples of high throughput phenotyping tools that provide quick insights into the uniformity and vigor of seeds (Mir *et al*., 2019). These non-destructive methods aid in the more effective screening of nano-primed seeds across vast populations.

Systems Biology: By using systems biology to integrate transcriptomic, proteomic, metabolomic, and phenomic data, comprehensive genotype-phenotype-environment models are produced. Predictive insights into how resilience pathways are shaped by nano-priming during climatic extremes are made possible by such models.

Conclusion

Next-generation seed priming with nano-biostimulants is a ground-breaking technique for enhancing germination in the face of climate extremes. By modifying physiological pathways, initiating molecular defenses, and combining with superior breeding and omics, nano-priming ensures rapid and robust crop establishment. More production is required due to the rising demand for nanomaterials. A variety of nanomaterials, including as metal and metal oxide nanoparticles, were employed in nano-priming to enhance seed germination and foster stress resistance. Similar to previous priming methods, nano priming increases tolerance to abiotic stressors, promotes plant growth, and causes synchronous germination.

References

Abbasi Khalaki, M., Moameri, M., Asgari Lajayer, B. and Astatkie, T. (2021). Influence of nano-priming on seed germination and plant growth of forage and medicinal plants. *Plant Growth Regulation*, 93(1): 13-28.

Ahmad, P., Abdel Latef, A. A., Rasool, S., Akram, N. A., Ashraf, M. and Gucel, S. (2016) Role of proteomics in crop stress tolerance. *Frontiers in Plant Science*, 7: 1336.

Mir, R. R., Reynolds, M., Pinto, F., Khan, M. A. and Bhat, M. A. (2019) High-throughput phenotyping for crop improvement in the genomics era. *Plant Science*, 282: 60-72.

Blum, A. (2010). Plant breeding for water-limited environments. Springer Science and Business Media.

Kamithi, K. D., Wachira, F. and Kibe, A. M. (2016). Effects of different priming methods and priming durations on enzyme activities in germinating chickpea (*Cicer arietinum* L.). *American Journal of Natural and Applied Sciences*, 1(1): 1-9.

Khadrji, A., Qaddoury, A. and Ghoulam, C. (2023) Positive Effects of Priming with Glucose and Sucrose on Seed Dormancy and Germination Parameters of Some Varieties of Chickpeas (*Cicer arietinum* L.). *International Journal of Agricultural Science,* 8: 172-177

Mirshekari, B. (2012). Seed priming with iron and boron enhances germination and yield of dill (*Anethum graveolens*). *Turkish Journal of Agriculture and Forestry*, 36(1): 27-33.

Mouradi, M., Bouizgaren, A., Farissi, M., Makoudi, B., Kabbadj, A., Very, A. A. and Ghoulam, C. (2016). Osmopriming improves seeds germination, growth, antioxidant responses and membrane stability during early stage of Moroccan alfalfa populations under water deficit. *Chilean Journal of Agricultural Research*, 76(3): 265-272.

Rahman, M. A., Yong-Goo, K., Iftekhar, A., Liu, G. S., Hyoshin, L., Joo, L. J. and Byung-Hyun, L. (2016). Proteome analysis of alfalfa roots in response to water deficit stress. *Journal of Integrated Agricultutre*, 15: 1275-1285.

Munns, R. and Tester, M. (2008). Mechanisms of salinity tolerance. *Annual Reviews in Plant Biology*, 59(1): 651-681.

Nakashima, K., Yamaguchi-Shinozaki, K. and Shinozaki, K. (2014) The Transcriptional Regulatory Network in the Drought Response and Its Crosstalk in Abiotic Stress Responses Including Drought, Cold, and Heat. *Frontiers in Plant Science*, 5: 170.

Pawar, V. A. and Laware, S. L. (2018) Seed Priming: A Critical Review, *International Journal of Biological Sciences*, 5: 94-01.

Roychowdhury, R., Das, S. P., Gupta, A., Parihar, P., Chandrasekhar, K., Sarker, U., Kumar, A., Ramrao, D. P. and Sudhakar, C. (2023). Multi-Omics Pipeline and Omics-Integration Approach to Decipher Plant's Abiotic Stress Tolerance Responses. *Genes*, 14: 1281.

Shomali, A., Das, S., Arif, N., Sarraf, M. Zahra, N., Yadav, V., Aliniaeifard, S., Chauhan, D. K. and Hasanuzzaman, M. (2022). Diverse physiological roles of flavonoids in plant environmental stress responses and tolerance. *Plants*, 11: 3158.

Singh, P., Choudhary, K. K., Chaudhary, N., Gupta, S., Sahu, M., Tejaswini, B. and Sarkar, S. (2022). Salt stress resilience in plants mediated through osmolyte accumulation and its crosstalk mechanism with phyto-hormones. *Frontiers in Plant Science*, 13: 1006617

Tavili A, S. Zare, S. A. Moosavi and A. Enayati, (2011). Effects of Seed priming on Germination characteristics of Bromus Species under Salt and Draught Conditions. *American-Eurasian Journal of Agricultural and Environmental Sciences*, 10(2): 163-168.

Varadharajan, V., Rajendran, R., Muthuramalingam, P., Runthala, A., Madhesh, V., Swaminathan, G., Murugan, P., Srinivasan, H., Park, Y., Shin, H. and Ramesh, M. (2025). Multi-Omics Approaches against Abiotic and Biotic Stress: A Review. *Plants*, 14(6): 865

Zhu, J., Zou, Z., Shen, Y., Li, J., Shi, S., Han, S. and Zhan, X. (2019). Increased ZnO nanoparticle toxicity to wheat upon co-exposure to phenanthrene. *Environmental Pollution*, 247: 108-117.

Indigenous Livestock Management for Sustainable Livelihood

Ramdas Bhimrao Shende, Jessy Bagh and Sharad Kale

Introduction

An essential component of agriculture, animal husbandry plays a major role in the socioeconomic development and rural economy of many emerging nations. Since the domestication of cattle for commercial purposes, the local customs and culture have been strongly associated with animals. For example, the goat is sacrificed during specific festivals and rites in both the Muslim and Hindu religions, whereas the cow is revered by the majority of Hindu populations in India. There are already over a billion people worldwide that depend directly on cattle for their livelihood and food security. Most of them have been in developing nations, where they own little land, lack guaranteed incomes from growing crops, and rely largely on raising animals to ensure their food security. Overall, there is good potential to increase these livestock's production with the implementation of appropriate systems and technology. However, because of their conventional mindset and lack of infrastructure to grow the value chain, many communities find it incredibly difficult and slow to modify the behaviors they currently follow.

The indigenous knowledge (IK) tuned to local culture, social system, need based, tested over the centuries, dynamic in nature allow the local people to adapt to social and ecological attributes and play an important role for food security and overall enhancement of the sustainability of natural resources (Singh and Sureja, 2007). Indigenous knowledge is ingrained in community customs, institutions, and cultural rituals and serves as the foundation for local decision-making in the areas of agriculture, health and natural resource management. It is an underutilized resource in the development process, implicit in nature, and difficult to codify. For ages, resources have been successfully maintained by locally developed institutional arrangements run by stable communities, but they frequently break down when fast change takes place. The importance of livestock as an integral component of agriculture has long been maintained by Indian farming traditions.

In particular, native animal species including Murrah buffaloes, Gir, Tharparkar cows, Sahiwal, and Jamunapari goats have provided milk, draught power, and natural manure to maintain the fertility of

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the soil. Genetic characterization of Indian breeds of cattle is fundamental in working out breeding strategies and conservation plans. Gene markers can be broadly exploited to access genetic variability as they contribute information on every region of the genome. Microsatellite markers can be used as one of the most powerful means for studying the genetic diversity (Putman and Carbone, 2014). The importance of bullock power in the Indian agricultural sector has decreased recently due to land holding fragmentation and mechanization, which has severely neglected several draft breeds and contributed to the ongoing decline of the country's native cow population. Over the past ten years, the introduction of extremely productive temperate breeds for cross-breeding to boost milk production has also contributed to a decline in the population of Indian cow breeds. In India, cattle have been crossed purely for the purpose of increasing milk output, ignoring the enormous potential of native breeds, such as their high adaptation qualities to survive and thrive in harsh climates (Livestock Census, 2012).

Why Indigenous Livestock Breeds Matter to Farmers?

Indigenous livestock are naturally suited to Indian agro-climatic conditions. They possess excellent heat tolerance, disease resistance, and the ability to thrive on locally available feed resources. Desi breeds are generally low-maintenance, making them ideal for small and marginal farmers. Beyond milk and meat, their dung and urine play a crucial role in enhancing soil organic matter, improving microbial life, and providing a reliable source of farmyard manure (FYM), which supports soil fertility. In rainfed and resource-poor areas, these hardy animals ensure livelihood security while contributing to soil restoration, making them indispensable in sustainable agriculture systems.

Economic Importance of Indigenous cattle

Dairy is the most important agricultural product, directly employing over 8 crore farmers and making up 5% of the national GDP. India leads the world in milk production, accounting for 23% of global output. India's milk production increased at a compound annual growth rate of roughly 6.2% from 146.31 million tons in 2014-15 to 209.96 million tons in 2020-21. In 2022-23, the country's total milk production was 230.58 million tons, with 459 g of milk available per person (DAHD, 2021-22). Traits of economic importance are those traits that influence the overall economy of the farm. These can be denoted as sum of Genotype (G) and Environment (E) constituting the Phenotype (P). Genotypic traits include those traits connected with that of species, breed, strain, and/or variety. Numerous genes of economic significance may be found in the highly developed gene pool seen in Indian cow breeds. Numerous of them are renowned for their capacity to adapt to the agro-climatic conditions of the area, their resilience to severe weather and tropical diseases, and their ability to survive when fed inadequately and produced using low-input methods. The overall usefulness and contribution of native cattle should be taken into account in order to determine their true economic worth. These include lifespan productivity, the market value of locally produced animal products, ecosystem preservation, low-input production system productivity and sustainability, social and cultural value, climate-resilient traits, and animal waste valuation.

Practical Livestock Management Practices for Farmers

Livestock productivity is increased and losses are decreased with proper care, feeding, and preventative health management. Animal performance is limited by the majority of farmers' continued heavy reliance on dry feed alone. Milk yield, animal weight, and reproductive efficiency are all increased by a scientifically balanced diet that combines dry fodder, green fodder, and concentrate feed. Locally grown green fodders like berseem, maize, jowar, and bajra should be cultivated seasonally to support livestock feed needs. Green fodder also benefits soil by preventing erosion and adding organic matter through leftover crop residues. A small daily supplement of concentrate feed (grains, oil cakes, bran) and mineral mixture ensures balanced nutrition. Fresh, clean drinking water should be made available to animals throughout the day. Housing should be well-ventilated and shaded with trees or natural shelters to minimize heat stress. Regular deworming and preventive vaccinations against common diseases like Foot and Mouth Disease (FMD), Hemorrhagic Septicemia (HS), and Black Quarter (BQ) are necessary to maintain livestock health.

Livestock Role's in Soil Health Improvement

Indigenous livestock are vital for organic nutrient recycling on farms. Their dung, when properly collected and composted, produces FYM rich in organic matter and essential plant nutrients. Regular application of FYM improves soil structure, water-holding capacity and microbial activity while supplying balanced nutrients to crops. Vermicomposting, which uses earthworms to turn manure into premium, nutrient-rich organic compost, is another way farmers can enhance the quality of their manure. Vermicompost promotes the growth of beneficial soil bacteria and increases the availability of phosphorus in the soil. The slurry left over after gas generation is a beneficial organic fertilizer for farms that have biogas plants. This slurry adds organic carbon, phosphorus, potassium, and nitrogen to the soil when it is sprayed directly to fields. Growing green fodder benefits livestock nutrition and simultaneously improves soil health. Crops like berseem, Lucerne, maize, jowar, and cowpea enrich the soil by adding organic residues after harvest. Leguminous fodders also fix atmospheric nitrogen, naturally enhancing soil fertility. Fodder trees like Subabul, Ber, Khejri, and Neem planted on field bunds serve as shade, green fodder, and erosion control barriers. This system ensures year-round fodder availability, reduces pressure on natural pastures, and improve soil health through nutrient recycling.

Importance of conserving indigenous cattle and strategies involved

The greatest native cattle breeds in India are those that have both dairy and draft qualities, as well as dual-purpose traits, and are well suited to the agroclimatic conditions of their breeding region. The diversity of indigenous cattle must be preserved since the locally adapted cow breeds are classified as endangered or in varying conservation states. Their capacity to adapt to shifting conditions is weakened by the loss of genetic variety. The loss of cattle genetic diversity has been found to be augmented by intensification of production systems, lack of characterization of indigenous breeds adapted to a particular agro-ecological zone, and also inappropriate breed replacement by crossbreeding with high producing breeds to improve productivity (Naskar *et al.*, 2012). Given global warming and accelerating climate change, the preservation of native cow breeds becomes even more crucial. The lactation production of native breeds has been documented via the Central Herd Registration Scheme, and breeds such as Gir (3038-3263 kg), Ongole (2000-2544 kg), and Hariana (1671-4015 kg) have been identified as high yielders (Mandi *et al.*, 2018). Dwarf Malnad Gidda cattle, weighing between 80 and 120 kg, were found to produce 3-4 kg of milk daily with regular calvings, even in minimal input production systems.

Conclusion

Scientific management of indigenous live-stock, coupled with systematic manure and soil fertility practices, offers farmers a low cost, sustainable way to improve both productivity and profitability. Indigenous breeds provide consistent returns in milk, meat, and organic manure. Their dung, when processed as FYM, vermicompost, or biogas slurry, naturally restores soil health, improves crop yields, and reduces chemical fertilizer dependence. The Long term sustainability of various native cattle breeds requires the use of sustainable livestock production and health practices. Making the most of cattle biodiversity is essential to sustainable food production, which raises food security. There are several biotechnology-based interventions available to identify appropriate local breeds and to conserve and manage them sustainably.

References

Naskar, S., Gowane, G. R., Chopra, A., Paswan, C. and Prince, L. L. L. (2012). Genetic adaptability of livestock to environmental stresses. In *Environmental stress and amelio-ration in livestock production* (pp. 317-378). Berlin, Heidelberg: Springer Berlin Heidelberg.

Singh, R. K. and Sureja, A. K. (2007). Dynamics of sustainable livestock and natural resources management. *Industrial Journal of Traditional Knowledge*, 6(4): 619-629.

Putman, A. I. and Carbone, I. (2014). Challenges in analysis and interpretation of microsatellite data for population genetic studies. *Ecology and Evolution,* 4(22): 4399-4428.

Livestock Census. (2012). BAHS-Basic Animal Husbandry Statistics: Department of Animal Husbandry, Dairying and Fisheries, Ministry of Agriculture, Government of India, New Delhi, 2012. Krishi Bhavan.

DAHD. (2021-22). Annual report, Department of Animal Husbandry and Dairying, Ministry of Fisheries, Animal Husbandry and Dairying, Govt. Of India.

Mandi, K., Subash, S. and Devi, M. C. A. (2018). Strategies for conservation and improvement of indigenous cattle breeds in Gaushalas. *Research Journal of Animal Husbandry and Dairy Science*, 9(1): 20-25.

Dry Flower Preservation

Rohan Tomar, Ramachandra Naik M. and Ajay Baldaniya

Introduction

Flowers have held an eminent place in art, religion, health, and culinary since ancient times. Particularly, the popularity of edible flowers has increased since the late 1980s. The market of edible flowers is becoming more important due to the increased number of recipe books, magazine articles, and websites on the theme, as well as to the growth of research on their nutritional and bioactive potential (Rop *et al.*, 2012). However, the market for edible f lowers still receives less attention than that of other products, such as vegetables and fruits, because the production of edible flowers is still low and it is still a niche market. With a limited shelf life of two to five days following harvest, edible flowers are extremely perishable. They also exhibit early petal abscission and discoloration, floral wilt, dehydration, and tissue browning. Because their stems are cut very short and they are not given extra water to keep them fresh, edible flowers are more susceptible to damage than cut flowers used for adornment. Flowers' economic viability is limited by certain publications' recommendation that they be gathered on the same day as they are to be consumed. Until far, no recommendations have been established for storage of edible flowers and few extensive studies have been done on the elements that limit their quality (Kou *et al.*, 2012). Presently, most edible flowers are sold fresh, packaged in small, rigid plastic (or plastic wrapped) packages and placed next to fresh herbs in refrigerated sections. Fresh flowers are really pretty, but they're also pricey, fleeting, and only available in certain seasons. In contrast, goods made from dried flowers remain a long time and maintain their aesthetic appeal throughout the year. For hundreds of years, the practice of preserving plant materials in a dried state has been regarded as an art form. Flowers have long been known to be dried, but Germany was the first country to dry flowers professionally. Numerous attributes are provided by the dried ornamental products, including uniqueness, durabi-lity, visual appeal, adaptability, and year-round availability. Dried ornamental plant pieces are highly after for their durable and appealing look and are typically less priced. Indian export of flowers is composed of 71% dry flowers exported mainly to USA, Japan, Australia, Russia, and Europe. India is one of the major exporters of dry

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flowers to the tune of 5 percent world trade in dry flowers. This Industry shows a growth rate of 15 percent annually. The market for the dry flower has grown exponentially as consumers have become "eco-conscious" and choose dry flowers as the environment friendly and biodegradable alternative to fresh flowers.

Benefits of Preserving Flowers

Long-Lasting Beauty: Dried flowers can last for years, allowing you to enjoy your favorite blooms indefinitely.

Decorative: Preserved flowers can be used in a variety of creative ways, from wreaths to framed displays.

Sentimental Value: Drying flowers from a special event helps preserve the memories associated with them.

Sustainable Decor: Using dried flowers in your home is an eco-friendly way to decorate, as they require no water or maintenance.

Techniques for Drying Flowers

Air drying: Air drying is the most traditional and inexpensive method of drying flowers. In this method, good quality flowers at a slightly immature stage are selected and foliage is removed from the flowers. The flowers in bunches are then tied inverted either in a warm dark area or in sunlight hence it is also called as Upside Down or Hang and Dry method of drying. It shoudd be noted that discolouration can happen if the flowers are dried in direct sunlight, so shade drying must be preferred to keep the floral pigments intact. The duration for drying greatly depends upon the moisture content, temperature and humidity and can vary between 1-2 weeks. Flowers like strawflower, globe amaranth, cattail, statice, salvia, chrysanthemum etc. should be picked at the bud stage or partially opened as they continue to open while drying (Chakrabarty and Datta, 2021).

Water drying: Water drying is a simple and inexpensive method of flower drying or dehydration. In this method, the foliage or foliage is initially placed in a few centimetres of water. Then the water is allowed to slowly evaporate. The container along with flowers should be kept in a warm and dark location. Depending upon the moisture content in plant material, this method takes 6-7 days for drying. Plant materials suitable for water drying are corn-flower, gypsophila, hydrangea, cockscomb, Bells-of-Ireland etc.

Sun drying: Using the sun-drying method, the plant material is placed in a container and rapidly dried in the sun. Common materials for sun drying include eucalyptus, palm leaves, poppy and lotus pods, cornflowers, and more. In addition, flowers like pansies, marigolds, before being exposed to the sun, zinnias and pompon chrysanthemums are dried by being embedded upside down in the sand. Sun-drying is the most used technique in India.

Press drying: In this method, it must be ensured that the water vapor completely escapes from the plants otherwise there is a risk of microorganism attack, failure of drying and loss of material. Drying sheets are placed in the oven at the optimal temperature; drying time can be reduced. A wide range of flowers and leaves as well as a big variety of unknown materials can be dried quickly by press drying. Gill *et al*. (2002) found that roses dried best in 120 hours, carnations in 132 hours, and helichrysum in 72 hours when press-dried. They added that in order to help the flowers dry, absorbent facial tissues might be placed on the pages.

Microwave drying: This is the quickest method of drying which generates little amount of heat also. It is based on the principle of liberating moisture by agitating water molecules in organic substances with the help of electronically produced microwaves. Drying in the microwave takes only 5-10 minutes for drying while in hot air oven flowers dry in 6-24 hours. The major advantage of rapid drying was improved retention of natural flower colour. Microwave oven drying is not suitable for all flowers. It is the best for flowers with many petals such as Marigold, Rose, Carnation and Zinnia.

Silica gel: Silica gel is the best desiccant for getting excellent quality dry flowers that retain colour and shape. It takes out the moisture from the flower part to expedite the drying process. Since it does not cause bleaching or brittleness to flower petals even if embedded for a long time, this method of drying is preferred by many. Anemone, Baby's breath, Bachelor's button, Cosmos, Gladiolus, Delphinium, Larkspur, Salvia, Sunflower etc. are suitable for drying using silica gel.

Glycerine drying: Glycerine drying has been used by several workers especially to preserve foliage. It was comparatively less expensive and has a high-water attracting capacity. Preserving foliage and berries in glycerine and hot water solution brought them into an almost everlasting category. It is found that glycerinizing replaced the water content of leaves giving them a strong and pliable nature. This method is found more suitable for eucalyptus, hydrangea, ivy and magnolia.

Special Operation used for Drying of Flower Processing: In this method, the internal moisture of the flowers is replaced with 2-propyl alcohol or t-butyl alcohol, where these solvents destabilize the moisture from the flowers, so that flower size is lost. As a result, an epoxy resin replacement procedure using an ascending chain of acetone. The colors precipitate out of the petals during drying because of the availability of water in the solvent in this process, which uses an ascending chain of ethyl alcohol.

Markham *et al*. (2000) used a moisture replacement procedure without using water-based solvents and found that the pigment diffused but stayed in dried flower petals. Dehydrated flowers with natural hues and textures can be created by utilizing simple mono-hydroxy alcohols and lateral chain diols.

Bleaching: Bleaching is one of the most important processes related to the production of commercial dried flowers. In the flowering plant materials that are sold in the market, bleaching is very significant. Bleaching is used to eliminate all or almost all of the colors that develop during the dehydration phase of the preservation process. There are two types of bleaching: oxidative and reductive, but the level of efficiency is determined by the measurement of the bleach's access to lignin. Sodium chloride, hypo-chlorite and peroxide are examples of oxidative bleaches, while sodium sulphide, hydrosulfite and dioxide are examples of reductive bleaches. Bleached ornamental plant material shows contrasting attractiveness when kept with dried or dyed ornamental plants. Bleaching also makes it possible to utilize dyes for coloring. Because it is relatively selective for lignin and causes minimal harm to the fiber, sodium chlorite is an effective bleaching agent. Hydrosulfites (sodium or zinc hydrosulfite) are less expensive than other bleaching chemicals.

Packaging, handling and storage: It is important that purchase of superior-grade or standard cartons or boxes for packaging should be preferred for packaging of delicate dried flowers and their products. A small quantity of silica gel at the bottom of the container to absorb any moisture. Different containers like glass desiccators, tin boxes, cartons wrapped with plastic sheets or wax paper can be used for storage of dried ornamental plant material.

Conclusion

For many years, dry flowers have been utilized for adornment and artistic expression. Additionally, there is a huge global market for dried flowers. One of the main reasons to pursue your passion of making, manufacturing, and developing dried plant material is the ease of access to a wealth of plant material. Dry flowers and foliages have a lot of potential as a substitute for fresh flowers since, unlike fresh flowers, which quickly lose their attractiveness and market value, they last longer if properly kept. Keeping in view the great scope in the dry flower industry, there is an immediate need to strengthen its market, financial assistance through government agencies and training for entrepreneurship development especially for women empowerment in India and through the export of dry flowers to different countries of the world.

References

Chakrabarty, S. and Datta, S. K. (2021). Value addition: Dehydration of flowers and foliage and floral craft. In *Floriculture and Ornamental Plants* (pp. 1-43). Singapore: Springer Singapore.

Markham, K. R., Ryan, K. G., Gould, K. S. and Rickards, G. K. (2000). Cell wall sited flavonoids in lisianthus flower petals. *Phytochemistry*, 54(7): 681-687.

Gill, S. S., Bakhshi, R. and Arora, S. (2002). Standardization of drying methods for certain cut flowers.

Kou, L., Turner, E. R. and Luo, Y. (2012). Extending the shelf life of edible flowers with controlled release of 1-Methylcyclopropene and modified atmosphere packaging. *Journal of Food Science*, 77(5): S188-S193.

Rop, O., Mlcek, J., Jurikova, T., Neugebauerova, J. and Vabkova, J. (2012). Edible flowers a new promising source of mineral elements in human nutrition. *Molecules*, 17(6): 6672-6683.

Role of Artificial Diet and Botanical Mediated Serifeed for Sericulture Industry

Rubi Sut, Toko Naan and Priyangana Chetia

Introduction

The English term "culture" means "rearing," and the Chinese word "Su (Si)" means "Silk." These two words have been merged to form the phrase sericulture. The adult silk moth's caterpillar is called a silkworm. The art and science of raising silkworms for the purpose of silk farming is known as sericulture. Manufacture of raw silk and silk as the final product. Sericulture is the broad term for the business procedures used to produce silk from silkworms. Sericulture, often known as silkworm farming, is a globally significant agricultural sector whose influence on commerce and culture has made it an essential component of the human narrative. Mulberry cultivation has its roots in ancient China, the birthplace of civilization, where it first appeared about 2600 BC (San, 2014). This industry has contributed to numerous nations' economies thrive and encouraged cross-cultural interaction over time. With decades of history, India has emerged as a leader in the production of silkworms, building on a millennium-old tradition that is ingrained in its cultural heritage. Mulberry and Non mulberry are the two major subsectors of sericulture. Producing silk from mulberries is the focus of mulberry sericulture, while producing silk from eri, tasar, and muga is the focus of non-mulberry sericulture. *Bombyx mori* L., a silkworm, is monophagous. It only consumes mulberries because of the chemical morin. The development and growth of larvae, as well as the subsequent production of cocoons, are significantly influenced by the nutritional value of mulberry leaves. Nutrition is essential to silkworm sericulture since it improves the commercial characteristics of the silkworm. Almost all of the nutrients required for the monophagous silkworm to thrive are found in mulberry leaves. The mulberry (*Morus* sp.), the only plant needed for sustenance, is essential to the growth of the silkworm and, eventually, to the production and productivity of silk (Bhaskar *et al*., 2008). The most recent methods in sericulture research involve supplementing or fortifying mulberry leaves. Studies are being conducted to determine the effects of nutrient supplement fortification, including the addition of proteins, carbs, amino acids, vitamins, sterols, hormones, antibiotics, and others, to improve performance and

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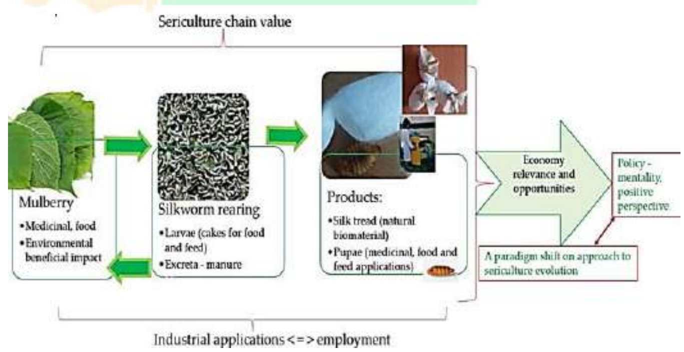
increase the productivity, quantity, and quality of cocoons. Numerous compounds, including vitamins, minerals, amino acids, soya protein, hormones, and plant extracts, have been added to mulberry leaves as supplements to enhance the characteristics of the cocoon, including the silkworm's reproductive capability (Nirwani *et al*., 1998).

Botanical Extract as a Supplementary Serifeed

It is commonly recognized that the nutritional value of mulberry leaves affects both the cocoons' economic qualities and the growth and development of silkworm larvae. The first significant development in the research of silkworm nutrition was the use of plant extracts. Using plant extracts to fortify mulberry leaves is standard procedure. Fortifying mulberry leaves with plant extracts to improve the nutrition of silkworms is one way to increase silk output in tropical countries like India. It was discovered that feeding *B. mori* mulberry leaves instead of spirulina orally improved the characteristics of the larvae and cocoons (Sangamithirai *et al.*, 2014). In several experiments, mulberry leaves have been treated with different nutritional substances before being fed in an effort to enhance their quality. Only a small amount of success has been achieved in its practical application, even though the majority of the information on technique, the concentration of various compounds, as well as the dosage and time of fortification, is available. Many food ingredients have been tested in different amounts, including glucose, starch, sucrose, calcium carbonate, calcium phosphate, calcium lactate, glycocoll, vitamins A and B, choline, hen's egg yolk, soybean oil, soybean protein glycine, and honey. Sufficient nutrition is essential for raising silkworms, and treating mulberry leaves with plant leaf extracts can increase silk output even in situations where food is scarce, leading to financial benefits. The worms' capacity to grow healthily is greatly influenced by the nutritional value of the leaves they are fed, which also has an effect on their economic traits and grain age measurements. Hiremath *et al*. (2009) investigated the total lipid content of silkworms at different stages of development that were fed mulberry leaves using organic nutrition management. Research on the effects of different fortification agents in silkworm nutrition can be evaluated using the cooperating supplements principle, which states that for many insects to meet their nutritional needs, supplemental or substitute sources of nutrients must cooperate with the species' commonly recognized food items.



Artificial Diet for Silkworm Rearing

In 1960, the first successful silkworm raising with an artificial feed was accomplished. When reared on an artificial diet at the time, the larvae had poor growth, high mortality, slow development, and little cocoons. It is currently not too difficult to raise silkworms on artificial feeds and obtain high-quality cocoons on a laboratory scale. The necessity for mulberry gardens, which are kept up to date to meet the unique nutritional requirements of immature instar silkworms, was eliminated with the development of artificial diets. The popular and fruitful silkworm hybrids that are commercially exploited in India, as well as their parent strains, were unable to withstand the artificial diet and had a low FR (Feeding Response), in contrast to early predictions.

Composition and Formulation

The composition of artificial diets is critical to their success (Dong *et al*., 2017). Formulations vary depending on the specific developmental stage of the silkworm, from larvae to pupae. The diet must be adjusted to meet the changing nutritional needs throughout the lifecycle. Typically, these diets are formulated to include:

Proteins: Sourced from soybean meal, fishmeal or other protein-rich ingredients to support growth and development.

Carbohydrates: Provided by cereal grains or starches to supply energy.

Vitamins and Minerals: Essential micronutrients are added to prevent deficiencies and support overall health.

Additives: Enzymes, growth regulators and other additives may be included to enhance digestibility and growth rates.

Advantages of Artificial Diets

Consistency and Control: Artificial diets provide a consistent nutritional profile which helps in standardizing silk production. Unlike mulberry leaves which can vary in quality and nutrient content, artificial diets ensure that silkworms receive a balanced mix of proteins, carbohydrates, vitamins and minerals.

Reduced Dependence on Seasonal Variations: Climate and seasonal variations have an impact on mulberry agriculture, which causes variations in leaf availability. Artificial diets help to address this problem by providing a consistent food source regardless of environmental circumstances, allowing silkworm production to occur all year round.

Cost Efficiency: Although the initial setup for artificial diets may be higher, the long-term costs can be reduced due to lower dependency on mulberry plantations. This can be especially beneficial in regions where mulberry cultivation is not feasible or is economically unviable.

Enhanced Management: Artificial diets simplify the management of silkworms by reducing the labour involved in harvesting and preparing mulberry leaves. This allows sericulturists to focus on other aspects of silk production and improves overall efficiency.

Earlier Research Work

L-ascorbic acid (vitamin C) has traditionally been thought to be essential for *Bombyx mori's* growth and development. The only food source for silkworms is mulberry leaves, really contains considerable levels of ascorbic acid, but they are unable to synthesize it. The amount of ascorbic acid often added to silkworm food (enrichment) ranges from 1 to 2 percent of the dry weight of the artificial diet, which is thought to be the ideal ascorbic acid content. Singh *et al*. (2005) found that feeding silkworm larvae mulberry leaves treated with *Lactobacillus plantaram* improved the larval body weight, cocoon weight, shell weight, and pupation percentage. Nevertheless, no research has been done on *L. plantarum* colonization in the silkworm gut. Given the critical role that vitamin absorption plays in the nutrition and development of silkworms, Kamala and Karthikeyan (2019) investigated the effects of riboflavin nanoparticle supplementation on the economic characteristics and growth of the silkworm, *B. mori* L. When compared to control, they found that vitamin B_2 nanoparticles had a beneficial effect and markedly increased the larvae's growth (28.985%), silk gland weight (111.392%), and silk yield (194.44%). Joyce *et al*. (2020) studied Influence of Mushroom Silver Nanoparticles Enriched Mulberry, a Feed Supplement of Silkworm *Bombyx mori* L. on its Growth Parameters and found significant results on rearing performance. Nano-particles of aminoacids significantly enhanced the growth of the larvae, silk gland weight and cocoon parameters when compared to control. So amino acid nanoparticles can be used as a fortification agent for improving the silk production.

Conclusion

It was widely held that silkworms could not be raised on artificial diets through all phases of growth in order to make silk because of the high cost of the food. However, the development of inexpensive artificial diets and the breeding of poly-phagous silkworms may make this approach possible. Theoretical and practical research is currently being done on the creation of artificial diets, the creation of a rearing system, a cost-benefit analysis of the silkworm rearing system on artificial diets throughout the instars, and the effective production of silkworm eggs. It is projected that the new method of producing silkworms on artificial diets, which is a refurbished technology, will proliferate rapidly in sericulture. Before the quality of artificial diets can be improved, the quality of mulberry leaves must be improved.

References

Bhaskar, R., WolkoleSori, N., Shashidhar, K. R. and Gowda, A. N. S. (2008). Combined effect of bioinoculants and medicinal plant extract on rearing performance of silkworm, Bombyx mori L. (PM× CSR2). In *Proceedings of the 21st international sericultural congress. Athens: Greece* (pp. 90-5).

Hiremath, S., Srikar, L. N., Swamy, N. T. K. and Shashidhar, K. R. (2009). Lipid profile of silkworm, *Bombyx mori* as influenced by mulberry grown through organic based nutrient management. *Journal of Biological Sciences,* 1(1): 101-4.

Joyce, M. I., Delighta, M. and Sabura, R. (2020). Influence of mushroom silver nanoparticles enriched mulberry, a feed supplement of silkworm *Bombyx mori* L. on its Growth Parameters. *Sadakath: A Research Bulletin,* 7 (2): 50-59.

Kamala, M. and Karthikeyan, A. (2019). Effect of nutritional fortification of nanoparticles of riboflavin on the growth and development of Mulberry silkworm, *Bombyx mori* L. *Research Biotica*, 1(1): 23-30.

Nirwani, R. B., Hugar, I. I. and Kaliwal, B. B. (1998). Supplementation of riboflavin on economic parameters and biochemical changes of the silkworm, *Bombyx mori* L. *Bulletin of Sericicultural Research*, 9: 37-41.

San, T. K. (2014). *Dynastic China: an elementary history*. The Other Press.

Sangamithirai, A. V., Selvisabhanayakam, N. S., Ganeshprabhu, P. and Mathivanan, V. (2014). Studies on the quantitative parameters of Silkworm *bombyx mori* (L.) (Lepidoptera: Bombycidae) fed with control and spirulina treated Mr2 Mulberry leaves. *International Journal Modern Research and Reviews*, 2: 79-82.

Singh, K. K., Chauhan, R. M., Pande, A. B., Gokhale, S. B. and Hegde, N. G. (2005). Effect of use of Lactobacillus plantarum as a probiotics to improve cocoon production of mulberry silkworm *Bombyx mori* (L). *Journal of Basic and Applied Sciences*, 1: 1-8.

Mycorrhiza: A Living Tool

Shivam Dinkar, K. Babu Rao and Ramachandra Naik M.

Introduction

Sustainability refers to productive performance of a system over time. It implies use of natural resources to meet the present needs without jeopardizing the future potential. The Technical Advisory Committee of the Consultative Group on International Agricultural Research has defined sustainability as "successful management of resources for agriculture to satisfy changing human needs while maintaining or enhancing the quality of the environment and conserving natural resources". Currently, there is considerable resistance against the use of chemical pesticides and fertilizers because of their hazardous influence on the environment, and on soil, plant, animal, and human health. Hence, use of microbial inoculants, including mycorrhizal fungi is recommended in practical agriculture. Albert Bernhard Frank first used the term "mycorrhiza" to refer to the symbiotic relationship between fungi and plant roots. The word mycorrhiza literally translates to "fungus root." Mutualism between some fungi and the roots of higher plants produces mycorrhiza. Fossil mycorrhiza discovered in carbonaceous deposits suggest that mycorrhizal fungi coevolved with plants for more than 400 million years to form a part of the root system, despite the fact that the term "mycorrhiza" was only first used in 1885. These soil-dwelling fungus are found all over the planet and coexist symbiotically with the roots of the majority of terrestrial plants. It is unusual for a plant to lack a mycorrhizal root system in natural environments. Consequently, it may be claimed that mycorrhizal association is a widespread or almost universal phenomenon throughout the kingdom of plants. Arbuscular mycorrhizal fungi (AMF) play an important role in vegetation restoration because of symbiosis with plant root; they can facilitate mineral absorption by the host plant, stabilize and improve soil structure, affect the population structure and preserve species diversity (Bothe *et al*., 2010). They are key components of the soil biota and account for about 25% of agricultural soil microbial biomass. The major types of mycorrhizae are ecto and endo mycorrhizae. The ecto mycorrhizae are characterized by an extra cellular fungal growth in the root cortex. The ecological role of mycorrhizal fungi extends beyond individual plant health; it influences plant community structure and dynamics, ecosystem prod-

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uctivity, and the stability of various ecosystems (Hartnett and Wilson, 2002). In grasslands, for instance, mycorrhizal fungi have been shown to significantly affect the composition and diversity of plant species, with implications for overall ecosystem function. This is particularly relevant in India, where grasslands support a variety of native species and are integral to the livelihoods of many rural communities.

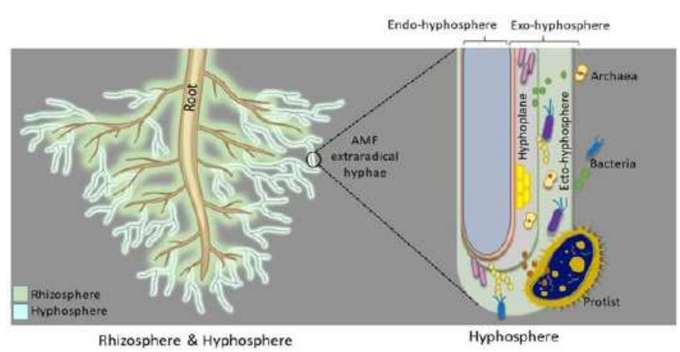
Types of Mycorrhizae

Mycorrhizae are primarily categorized based on the type of fungi involved and changes in the morphogenesis of fungi and roots. These are grouped as follow:

Ectomycorrhizae: It is characterized by the presence of hyphal plexus between root cortical cells producing a net like structure called 'Hartig net'. The fungal partner in an ectomycorrhizae most frequently belongs to the Basidomycota though in some cases, it an ascomycete.

Endomycorrhizae: The fungal hyphae that infiltrate the host root tissues' cortical cells are what define endomycorrhizae. Both septate and aseptate fungi are included in it. They have both internal and intercellular hyphae within roots, and they lack an outer sheath. All agronomic crops exhibit this kind of connection, which essentially falls into three groups: (i) *Ericaceous mycorrhizae*, (ii) *Orchidaceous mycorrhizae* and (iii) Arbuscular mycorrhizal fungi (AMF).

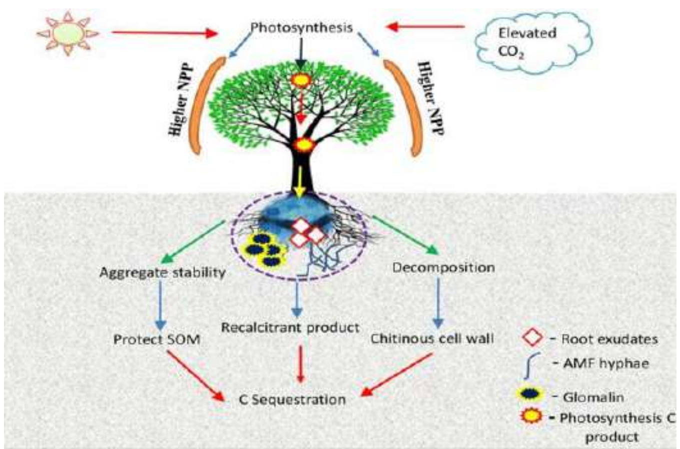
Arbuscular mycorrhizal fungi (AMF): These Fungi are characterized by the presence of intra-cellular hyphae in the primary cortex which form vesicles and arbuscular later on. Arbuscules are so named by Gallaud (1905) because they look like trees. Vesicles are thin-walled or thick-walled globose to subglobose, irregular shaped structures. AMF are found in all angiospermic families, except some families such as Betulaceae, Urticaceae, Commelinaceae, Cyperaceae and Polygonaceae. Earlier, the name Vesicular Arbuscular Mycorrhizal (VAM) fungus was used, but since not all the groups produce vesicles, the term AMF is preferred. Some of the important genera are *Glomus*, *Acaulospora*, *Gigaspora*, *Scutellospora*, *Enterophospora* and *Sclerocystis*. There are 106 species of six major genera of AMF known to exist in India, and they are more prevalent in farmed areas than in uncultivated ones. Sixty species of Glomus, fourteen species of *Acaulospora*, twelve species of *Gigaspora*, fifteen species of *Scutellospora*, three species of *Entrophospora*, and two species of *Sclerocystis* are representative of these fungi (Gupta and Mukerji, 2001).



Significance of AMF

Nitrogen uptake: Nitrogen is needed for the formation of amino acids, purines, pyrimidines and, is thus, indirectly involved in protein and nucleic acid synthesis. AMF associated plants have increased nitrogen content in shoots. A number of mechanisms are suggested for this effects, namely (i) improvement of symbiotic nitrogen fixation; (ii) direct uptake of combined nitrogen by mycorrhizal fungi; (iii) facilitated nitrogen transfer, a process by which a part of nitrogen fixed by nodulated plants benefits the non-nodulated plants; (iv) increased enzymatic activities involved in nitrogen metabolism like pectinase, xyloglucanase and cellulose which are able to decompose soil organic matter. The hyphae of AMF have the tendency to extract nitrogen and transport it from the soil to plants. They contain enzymes that breakdown organic nitrogen and contain nitrogen reductase which alters the forms of nitrogen in the soil.

Phosphorus uptake: Phosphorus is a major plant nutrient required in relatively large amounts and plays a vital role in all biological functions in energy transfer through the formation of energy-rich phosphate esters and is also an essential component of macromolecules such as nucleotiodes, phosphor-lipids and sugar phosphates. Increased soil exploration, increased phosphorus translocation into plants through arbuscules, altered root environment, efficient P utilization within plants, efficient P transfer to plant roots, and increased storage of absorbed P are some of the mechanisms put forth to explain increased nutrient uptake. Phosphate is absorbed by roots far more quickly than ions diffuse to the root's absorption surfaces (Bhat and Kaver-iappa, 2007). This results in a zone of phosphate deficiency surrounding the roots. In order to cross the zone of nutrient deprivation, the vast extrametrical hyphae of AMF reach several centimeters into the soil.



Supply of organic mineral nutrients: Although many mycorrhizal fungi can access inorganic forms of N and P, some litter-inhabiting mycorrhizal fungi produce proteases and distribute soluble amino compounds through hyphal networks into the root. The extrametrical hyphae of AMF take up and transport potassium (K), calcium and sulphates and AM colonization affects the concentration and amounts of K in shoots. AM plants accumulate large quantities of some micronutrients (Zn, Cu, Co) under conditions of low soil nutrient availability. The absorption is attributed to the uptake and transport by external hyphae due to wider exploration of soil volume by extended extrametrical hyphae. Uptake and concentration of manganese (Mn) in plants may not be affected by AM and more often it may be lower in AM plants, thus contributing to higher Mn tolerance in plants.

Carbon cycling: Significant amount of carbon flows through mycorrhizal mycelia to different components of soils. Production of glycoproteins such as glomalin that are involved in the formation and stability of soil aggregates may have also an important influence on other microorganisms associated with the AMF mycelium (Johnson *et al*., 2004).

Effects on plant community and ecosystem: The floristic diversity and productivity of plant community have been shown to depend upon the presence of species rich assemblage of AMF species. Increasing fungal diversity resulted in greater species diversity and higher productivity. The mechanism behind these effects is likely to be differential effects of specific plant fungus.

Conclusion

Mycorrhizal fungi are currently known to give a wide scope of huge advantages to their plant host. In addition to enhancing mineral nutrition, they prompt more prominent protection from soil pathogens, improve resilience to drought stress and decrease sensitivity to harmful substances occuring in the soil. Mycorrhizal colonization in plant root improves mineral supplement uptake and plant development. Macronutrient concentration and uptake as well as micronutrient concentration might be a productive strategy to use environment friendly biofertilizer rather than chemical fertilizer. AM fungi play significant roles in agroecosystems, including the contribution of the extraradical mycelium in giving soil aggregation. Glomalin has been demonstrated to be related with soil soil aggregate water stability.

References

Kawalekar, J. S. (2013). Role of biofertilizers and biopesticides for sustainable agriculture.

Bothe, H., Turnau, K. and Regvar, M. (2010). The potential role of arbuscular mycorrhizal fungi in protecting endangered plants and habitats. *Mycorrhiza*, 20(7): 445-457.

Hartnett, D. C. and Wilson, G. W. (2002). The role of mycorrhizas in plant community structure and dynamics: lessons from grasslands. *Plant and Soil*, 244(1): 319-331.

Gallaud, I. (1905). Études surles mycorrhizes endotrophes. *Reviews in gén. Botany*, 17: 479-500.

Gupta, R. and Mukerji, K. G. (2001). Microbial technology. A.P.H. Publishing Crop, New Delhi. pp: 233.

Bhat, P. R. and Kaveriappa, K. M. (2007). Effect of AM fungi on the growth and nutrition uptake in some endemic Myristicaceae members of the Western Ghats, India. *The Mycorrhizae: Diversity, Ecology and Application. Daya Pub. House, Delhi*, 295-309.

Johnson, D., Leake, J. R., Ostle, N., Ineson, P. and Read, D. J. (2002). In situ13CO_2 pulse-labelling of upland grassland demonstrates a rapid pathway of carbon flux from arbuscular mycorrhizal mycelia to the soil. *New Phytologist*, 153(2): 327-334.

Parthenocarpic Cucurbits: Exploring Seedless Fruit Development

Sudhama V. N., Ramachandra Naik M. and Sandeep Kumar

Introduction

The Cucurbitaceae family encompasses numerous commercially important crops that yield fruits known as cucurbits, including cucumber (*Cucumis sativus* L.), melon (*Cucumis melo* L.), watermelon (*Citrullus lanatus* L.), squash/pumpkin (*Cucurbita* spp.), bitter gourd (*Momordica charantia* L.), and bottle gourd (*Lagenaria siceraria* L.). As with other monoecious plants, successful fruiting in cucurbits depends on favorable pollination conditions (Gou *et al*., 2022). In the absence of pollinators or in unfavorable environmental circumstances, yield may be decreased. Circumstances, such low light levels, high humidity, or high temperatures. Parthenocarpy comes from the Greek words “Parthenos” (virgin) and “karpos” (fruit). Noll introduced the term “parthenokarpie” in 1902. Winkler defined parthenocarpy later in 1908. Parthenocarpy (literally, “virgin fruit”) refers to the natural or artificial production of fruit without ovule fertilisation. The fruits are either non-viable or seedless. Parthenocarpy is a process that limits female fertility and allows for the growth of seedless fruits without fertilization.

This has been observed in banana, tomato, water-melon, grapes and cucumber. The issue of low fruit set brought on by unfavorable pollination conditions may be resolved via parthenocarpy. Without requiring pollination or fertilization, parthenocarpy promotes fruit set and development, improving fruit set and guaranteeing steady fruit output even under challenging circumstances. Customers like parthenocarpic fruits because they don't have seeds, which enhances flavor and extends shelf life. They also eliminate the need for customers to remove the seeds. In addition, parthenocarpy greatly reduces the labor of artificial pollination frequently required to increase the yields of cross-pollinated Cucurbitaceae crops. Therefore, parthenocarpy is a highly beneficial agronomic trait for crops within the Cucurbitaceae family. Parthenocarpy is classified as either natural or induced, depending on whether exter nal stimuli are required. Natural parthenocarpy can be divided into two forms: obligate and facultative. Obligately parthenocarpic plants, such as pineapple (*Ananas comosus*), always produce seedless fruits, meaning that they must propagate through vegetative organs; in facultative parthenocarpy, seedless fruits

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only develop if pollination and fertilization are prevented (Varoquaux *et al*., 2000). Facultative parthenocarpy has greater potential for the breeding of Cucurbitaceae crops, which are usually propagated through seeds (Klap *et al*., 2017).

Classification of Parthenocarpy

Natural parthenocarpy: Seedless fruits are produced by the ovaries in the absence of pollination and fertilization, with no external treatment. Natural parthenocarpy is the term used to describe the natural process of producing seedless fruits.

- ✓ **Obligatory parthenocarpy:** Genetic sterility has led to the production of fruit without seeds. Eg.: Ivy gourd (*Coccinia*) and certain cucumber genotypes produce seedless fruits by nature.
- ✓ **Facultative parthenocarpy:** Poor pollination and fertilization lead to the production of seedless fruits. Natural parthenocarpy in brinjal is seen only when the plants are exposed to chilling temperatures (7-10°C). This trait is only expressed in cold temperatures; however, when pollination temperature is favourable, normal fruit and seed set occur. E.g. Tomatoes, Brinjal.

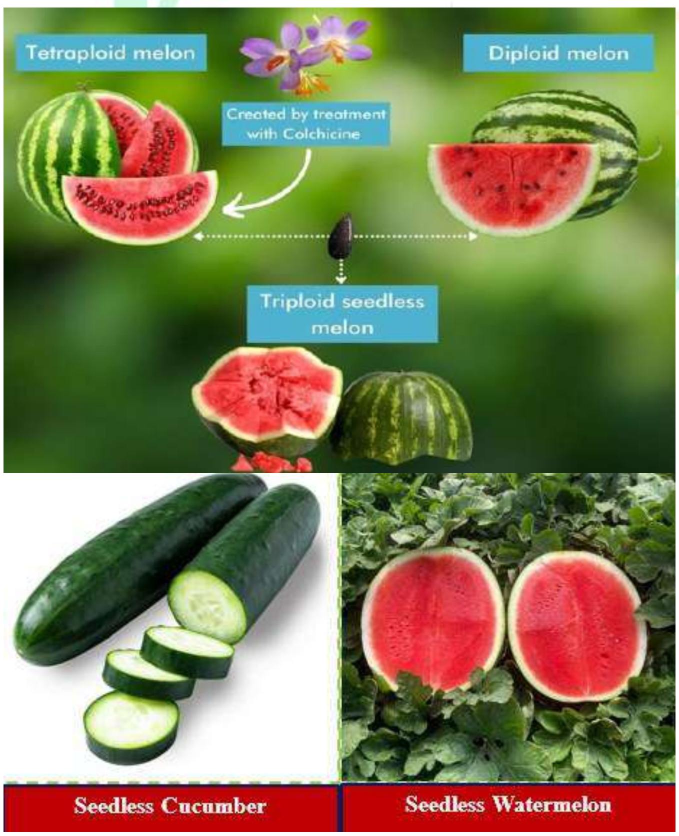
Induced parthenocarpy: In this situation, specific treatments are applied to the bloom to yield seedless fruits. As the name implies, induced (artificial) + parthenocarpy (production of seedless fruit). Parthenocarpy can be induced by using water extracts of pollen grains, irradiated pollen, application of plant growth regulators (Auxin, Gibberellin) and polyploidy breeding.

Germplasm and Genetic Mechanism of Parthenocarpy in Cucurbitaceae Crops

Growing seedless or parthenocarpic cucurbits is advantageous and lucrative for the following reasons: parthenocarpic varieties are typically early in nature, yield more than other seeded varieties and have a higher flesh content and higher nutritional value. Because they are seedless, they don't require pollinators like other cucurbits, which makes them ideal for protected cultivation, year-round production.

Cucumber (*Cucumis sativus* L.): Cucumber is cultivated as a vegetable worldwide. As the first crop plant recorded to exhibit parthenocarpy, cucumber has become a model organism for studying parthenocarpy, owing to its abundant germplasm. In an investigation of 201 cucumber germplasms representing various ecotypes, 124 accessions had a parthenocarpy rate of 50% or more and only 12 lines were identified as non-parthenocarpic. European greenhouse cucumbers exhibited a generally higher rate of parthenocarpy, whereas XSBN-type cucumbers showed the least parthenocarpy. According to Pike and Peterson (1969), parthenocarpy was controlled by a single partially dominant gene (P). PP (the homozygous dominant) develops parthenocarpic fruits early, typically, the first fruit appears by the fifth node. Whereas, the heterozygous Pp plants are less common and yield parthenocarpic fruits later than the homozygous plants. No parthenocarpic fruits are produced by the homozygous recessive pp.

Melon (*Cucumis melo* L.): At the moment, parthenocarpic melon resources are few, and no commercial cultivars are accessible. Fourteen accessions with a good parthenocarpic potential were identified from a screen of 172 accessions from an east Asian melon collection. The possibility that parthenocarpy may be inherited recessively and is probably regulated by the same gene or genes in these accessions is suggested by crosses between parthenocarpic accessions and a non-parthenocarpic cultivar (Yoshioka *et al*., 2018). It will take a lot of work to breed new cultivars with both parthenocarpic ability and high fruit quality because the fruit from these parthenocarpic accessions differs significantly from commercial cultivars in terms of shape, color, and sugar content.



Artificially Induced Parthenocarpy in Cucurbitaceae

Induction of Parthenocarpic Fruit by Hormone

Application: Auxin was the first hormone reported to induce parthenocarpy in plants. Auxin analogues induce parthenocarpy in Cucurbitaceae crops such as watermelon, cucumber, and zucchini, resulting in seedless fruit formation. The technique of this application should be taken into consideration when using auxin analogs topically to cause parthenocarpy in watermelon. When auxin analogs are applied locally to the watermelon ovary, the consequence is seedless watermelons with unfavorable traits such hollow cavities, thicker rinds, and reduced fruit sizes. Nevertheless, the seedless watermelons that come from spraying the entire plant do not differ significantly from pollination-produced watermelons. Gibberellin (GA) is another crucial plant hormone acting downstream of auxins in the control of plant parthenocarpy. Different gibberellins vary in their capability to induce parthenocarpy across species. For instance, GA3 strongly induces seedless fruit formation in tomatoes (*Solanum lycopersicum*), but does not effectively promote parthenocarpy in cucumbers (Qian *et al*., 2018). The application of exogenous brassinosteroids (BRs) (24-epibrassinolide, EBR) induces parthenocarpic growth accompanied by active cell division in cucumber cultivars without a parthenocarpic capacity, whereas treatment with a BR biosynthesis inhibitor (brassinazole, BRZ) inhibits the fruit set in cultivars with a natural parthenocarpic capacity.

Pollination-Induced Parthenocarpy: Fruit enlargement is stimulated by pollination with inactivated or incompatible pollen, producing fruits without seeds. When compared to fruits produced through conventional pollination, these fruits do not exhibit appreciable variations in quality or production. When diploid watermelon pollen is applied to the triploid watermelon's stigma, fruit development is induced, resulting in seedless watermelons. Parthenocarpic seedless diploid watermelons are produced by pollinating female flowers with pollen grains that have been exposed to X-ray or gamma radiation. While pollen from other Cucurbitaceae crops does not cause parthenocarpy in watermelons, Sugiyama *et al*. (2017) found that pollination watermelons with bottle gourd pollen can cause parthenocarpy, resulting in seedless watermelons. Nevertheless, the bottle gourd bears fruit by parthenocarpy following pollination with pollen from a variety of cucurbit species in addition to watermelon. It appears that the Cucurbitaceae are the only plant families that have reported inducing parthenocarpy through stimulation with pollen from a distantly related species.

Future scope of parthenocarpy

- ✓ Combine several genes with parthenocarpic gene.
- ✓ Developing parthenocarpy in high value crops to get more and early yield.
- ✓ Maintain and produce crops with stable level of parthenocarpy.
- ✓ Combine male sterility gene with parthenocarpy gene to improve yield and promote crossing.
- ✓ Improve character and quality of fruit.

Conclusion

In addition to producing seedless fruits, parthenocarpy is a valuable agricultural feature that speeds up fruit set in unfavorable environmental circumstances. Research on parthenocarpy in Cucurbitaceae crops has a significant impact on cultivar development. This trait turned out to be quite beneficial in greenhouse farming, particularly for vegetable crops like cucurbits that are heavily cross-pollinated. Although it is commonly known that phytohormones are essential for fruit setting, genetic manipulation of these hormones can cause seedlessness. The identification and efficiency of parthenocarpic genes in different crops can also be enhanced for the benefit of humanity through the application of biotechnology techniques.

References

Gou, C., Zhu, P., Meng, Y., Yang, F., Xu, Y., Xia, P., .. and Li, J. (2022). Evaluation and genetic analysis of parthenocarpic germplasms in cucumber. *Genes*, 13(2): 225.

Varoquaux, F., Blanvillain, R., Delseny, M. and Gallois, P. (2000). Less is better: new approaches for seedless fruit production. *Trends in Biotechnology*, 18(6): 233-242.

Pike, L. M. and Peterson, C. E. (1969). Inheritance of parthenocarpy in the cucumber (*Cucumis sativus* L.). *Euphytica*, 18(1): 101-105.

Yoshioka, Y., Shimomura, K. and Sugiyama, M. (2018). Exploring an East Asian melon (*Cucumis melo* L.) collection for partheno-carpic ability. *Genetic Resources and Crop Evolution*, 65(1): 91-101.

Qian, C., Ren, N., Wang, J., Xu, Q., Chen, X. and Qi, X. (2018). Effects of exogenous application of CPPU, NAA and GA_4+ 7 on parthenocarpy and fruit quality in cucumber (*Cucumis sativus* L.). *Food Chemistry*, 243: 410-413.

Sugiyama, K., Kami, D. and Muro, T. (2014). Induction of parthenocarpic fruit set in watermelon by pollination with bottle gourd (*Lagenaria siceraria* (Molina) Standl.) pollen. *Scientia Horticulturae*, 171: 1-5.

Bioinformatics in Sericulture

Toko Naan, S. Swetha and Bidisha Kashyap

Introduction

The English term "culture" means "rearing," and the Chinese word "Su (Si)" means "Silk." These two words have been merged to form the phrase sericulture. The adult silk moth's caterpillar is called a silkworm. The art and science of raising silkworms for the purpose of silk farming is known as sericulture. Manufacture of raw silk and silk as the final product. Sericulture is the broad term for the business procedures used to produce silk from silkworms. Sericulture, often known as silkworm farming, is a globally significant agricultural sector whose influence on commerce and culture has made it an essential component of the human narrative. Mulberry cultivation has its roots in ancient China, the birthplace of civilization, where it first appeared about 2600 BC (San, 2014). This industry has contributed to numerous nations' economies thrive and encouraged cross-cultural interaction over time. With decades of history, India has emerged as a leader in the production of silkworms, building on a millennium-old tradition that is ingrained in its cultural heritage. In India, sericulture is not only a tradition but also a living culture. It is a farm-based, labour intensive and commercially attractive economic activity falling under the cottage and small-scale sector. Though Indian silk industry occupies a predominant position in the world, its production is only 15% of total world production and more than 80% of production is contributed by China (Yaseen, 2013). Silk is the most elegant textile in the world with unparalleled grandeur, natural sheen, and inherent affinity for dyes, high a sorance, light weight, soft touch and high durability and known as the "Queen of Textiles" the world over. On the other hand, it stands for livelihood opportunity for millions owing to high employment oriented, low capital intensive and remunerative nature of its production. In the global sil commerce, Ndian sil exports' market share is this, given that India is the world's second-largest producer of raw silk, is hardly noteworthy. This is due to the sizeable domestic market for silk products in India, where around 85% of all produced silk goods are marketed. In the wake of international trade liberalization, India must raise the productivity and quality of its raw silk in order to compete with cheaper, higher-quality imported silk. He need of databases in sericulture field cannot emphasized more numerous organisms are involved in this field and scientists have uncovered minuscule information

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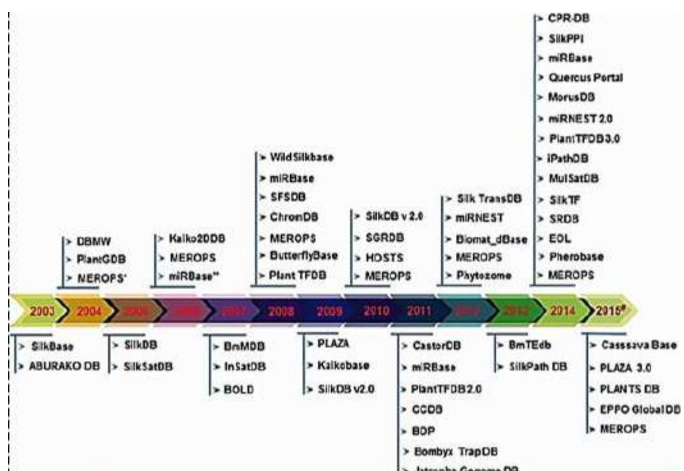
a out most of them while some are yet to identified second, the data that are generated in this field are of dissimilar type. Every piece of information, from gene maps, expression profiles, and biomaterials to nucleotide and protein sequences, is distinct and essential. Third, because sequencing, analysis, imaging, and other techniques are developing so quickly, a vast amount of data is produced (Singh *et al*., 2016). The primary requisite of a database is to provide good quality data. It must also have an optimal web interface with integral features like search, browse, data download, etc. Quality of data can be maintained by proper data deduction methods. These databases must be made openly accessible to others and equipped with analytical tools. This will promote better research and facilitate development of improved scientific strategies in this field. The Bioinformatics centre at Central Sericultural Research and Training Institute (CSRTI), Mysore was established as a sub node of the BTISnet in 1999 primarily to support the biotechnological research in sericulture. Maintain information repository of silkworm and mulberry genotypes and breeds. Develop and maintain the databases related to mulberry and silkworm genomes with structural information.

Database for Sericulture

There are currently 61 databases which comprise of genome, proteome, transcriptome and other data of silkworms, host plants, pest and pathogens, etc. There are currently roughly 20 databases accessible that contain silkworm specific data. These databases are classified as nucleotide (13 numbers), protein (04 numbers), genetic resource (02 numbers), and pathway (01 number) databases based on the data type (Dey *et al*., 2016).

MulDis: A Comprehensive Mulberry Disease and Pest Database: MulDis is an organism-specific database that contains details on the pests and illnesses that affect the silkworm and mulberry, the host plant. The database offers comprehensive details on the illnesses and pests, their locations, modes of infect-ion, biotic and abiotic factors, and the economical and environmentally responsible methods used to effectively control them.

SilkDis: A Comprehensive Silkworm Disease and Pest Database: An organism-specific database that includes details on the illnesses and pests of the silkworm and mulberry host plants. The database offers comprehensive details on the biotic and abiotic elements, location, mode of infection, diseases and pests and economical and environmentally respon-sible management techniques used.



Databases and for quick access to information on mulberry, silkworm and other allied

BioinfoLib: Specialized bioinformatics centers, books, scientific journals, manuals, newsletters, and information on the most recent research and development at those institutes on bioinformatics and related fields are all accessible through this Bioinformatics Library information system. This library will be available online via the center's URL, which all scientists, research students, and instructors at universities and research institutions can use.

Silkprot: An Annotated Protein database for Silkworm: SilkProt is a comprehensive, fully annotated, organism specific database for silkworm proteins. The database structure will support users to perform a BLAST search with highly specified and updated latest version of NCBI-BLAST server. In future this database will be extended for structure visualization and pathway information of silkworm proteins.

Objectives of Seri bioinformatics

- ✓ Organize a database of silkworm and mulberry genotypes and breeds.
- ✓ Develop and maintain databases containing structural information for mulberry and silkworm genomes.
- ✓ Conduct training/workshops in the subject of bioinformatics in general and Seri bioinformatics in particular, to raise awareness and increase visibility.
- ✓ To give sericulture-related assistance information via the internet.

Bioinformatics Tools Employed in the Silkworm Genome Sequence Analysis

The RAMEN software program was employed for *B. mori* sequence analysis that basically follows the overlap layout consensus paradigm. Individual steps follow the novel or state-of-the-art software, such as look-up table, generation of seed strings for highly sensitive and rapid detection of overlapping reads, precise alignment by efficient banded dynamic programming, a repeat untangling method of transforming a repeat sub-contig flanked by two unique sub-contigs into one unique contig, and an efficient multiple alignment algorithm utilizing seeds in the look-up table. BLAST searches are carried out using BLASTN ver.2.1.2. and alignments made using the criteria of >95% identity and >50 bp in length. The coverage was calculated as the ratio of the total length of alignments *B. mori* in WGS sequence contigs to the length of the query sequence (Mita *et al*., 2004). The whole *B. mori* sequence was analyzed and annotated using KAIKOBLAST and KAIKOGAAS.

KAIKOBLAST is a homology search system for analyzing silkworm sequence against nucleic acid and protein databases. It consists of nucleic acids and amino acids database search that utilizes the BLAST program for rapid search. The amino acid database search can be used for silkworm (p50T- Daizo strain) WGS sequence information. RAMEN assemble contigs and cDNA partial sequences from the KAIKO (cDNA database) confirmed gene set collection from WormBase; D. melanogaster full length cDNA sequences from BDGP DGC; D. melanogaster EST sequences from BDGP; WGS contig, scaffold and partial cDNA sequences from the Southwest Agricultural University; silkworm cDNA partial sequences from Zhejiang Sci-Tech University; Apis mellifera and A. cerana cDNA partial sequences, and BAC End sequence data. It is also useful for accessing the WormBase amino acid sequence (http://www.wormbase.org), PIR, SwissProt and NCBI non-redundant protein databases.

The KAIKO annotation table facilitates browsing the results of annotation, which is created using KAIKOGAAS through links from the BAC-clone table and the assembled WGS contigs table. Only WGS contigs with lengths of more than 5 Kbp are sorted. In the assembled WGS contigs table, a check-mark in the ORF column indicates ORFs of autopredicted genes in the contigs.

Application of Next Generation Sequencing Methods in Sericulture

The development of sequencing technologies has opened up new avenues and transformed researchers' methodologies. Deep insights into the molecular viewpoint of diseases have been made possible by the development of advanced molecular biology and computational biology, as well as the completion of the silkworm database. The use of big data and related analytical methods has aided in unraveling the secrets of non-coding RNAs, including small interfering RNAs and microRNAs. Genome Wide Association Studies have enabled researchers to identify and analyze Single Nucleotide Polymorphisms within a genome and their effect in disease biology. Several studies have been performed on transcriptional level of response silkworms against BmCPV which focused upon differential gene expression and miRNA targets (Gao *et al*., 2014).

Conclusion

In scientific research, *Bombyx mori* L. is considered as a model insect for molecular studies along with the fruit fly (*Drosophila melanogaster*) and a central model species for genome studies in moths and butterflies (the insect order Lepidoptera). As a consequence, new findings in the fields of proteome, genome and bioinformatics have resulted in the exponential generation of data that are stored in assorted array of databases. In the realm of biology, bioinformatics has completely changed how researchers understand and approach a given topic, as well as how experiments are conducted. Researchers will be able to examine protein-protein interactions and evaluate and interpret the outcomes of this process by using in-silico approaches. Additionally, computational biology offers the ability to conduct screening analyses before any traditional molecular biology experiment. The attempts to comprehend silkworms or their encounters with other living things have produced a wealth of data that has been transformed into various databases in electronic form. The use of contemporary techniques, such as next-generation sequencing, comparative modeling and simulation, docking, and the design of particular molecules, not only sheds light on the occurrence and progression of diseases in silkworms but also gives us the knowledge we need to improve the quality of silk fiber and give that silky touch. A useful seri-bioresource are these seri-bioinformatics databases.

References

San, T. K. (2014). Dynastic China: an elementary history. The Other Press.

Singh, D., Chetia, H., Kabiraj, D., Sharma, S., Kumar, A., Sharma, P., . and Bora, U. (2016). A comprehensive view of the web-resources related to sericulture. *Database*, 2016: baw 086.

Mita, K., Kasahara, M., Sasaki, S., Nagayasu, Y., Yamada, T., Kanamori, H., ... and Sasaki, T. (2004). The genome sequence of silkworm, Bombyx mori. *DNA Research*, 11(1): 27-35.

Dey, S. R., Singh, P. K., Ganguli, S. and De, M. (2016). Seri-Bioinformatics: To Enhance Silken Touch. *Environment and Socio-biology*, 13(2): 207-216.

Gao, K., Deng, X. Y., Qian, H. Y., Qin, G. X., Hou, C. X. and Guo, X. J. (2014). Cytoplasmic polyhedrosis virus-induced differential gene expression in two silkworm strains of different susceptibility. *Gene*, 539(2): 230-237.

Feeding and Reproductive Ecology of Rodent's

H. Vanlalhmuliana, C. Rachael and Lalthasangi

Introduction

In the agro-ecosystem, vertebrates have found an abundant supply of food and shelter. Throughout history, rodents, have been the most common vertebrate pest of field and storage items. Thus, significant efforts have been made to control and minimize the number of vertebrate pests and the extensive harm they cause (Witmer *et al*., 1995). The term rodent came from the Greek word 'rodere', meaning gnaw (Legendre, 2003). Rodents are characterised by prominent, contnuously growing incisors which are present in both the upper and lower jaw. Within the class Mammalia, rodents belong to the order Rodenta. They make up 40% of all mammals, with 35 families and more than 534 genera. All continents are home to rodents, with the exception of Antarctica, New Zealand, and a few minor islands. Rodents constitute the biggest group of mammals with around 2500 species having been reported from all around the world. Of the total rodent population, about 10% are considered as pests of agriculture, *i.e.*, about 200 species (Labuschagne *et al.*, 2016). Certain rodent species, such as *Rattus* sp. and *Musa* sp., can inflict harm ranging from 1 to 15%, and in certain circumstances, much more. Because they severely harm crops in fields and eat storage grains and vegetables, rodents are significant agricultural pests (Elango *et al*., 2022). They also ruin crops after harvest. The rodents feed on the germ which results in failure of germination in the grains and also are responsible for a reduction in the market value due to contaminate of grains with their urine, feces and hair. Additionally, rodents also act as vectors of more than 60 zoonotic diseases like typhus, plague, trichinosis, etc. which have serious implications on health of humans. Compared to the management of insects and diseases, vertebrate pests are still mainly unknown. According to Cao *et al.* (2002) rodents were responsible for approximate losses of 25% and 25-30% in grains, in pre harvest and post-harvest situations respectively, resulting in a loss of US$ 5 billion annually. Some common species of rodents found in India are: Indian field mouse, (*Mus booduga*), lesser bandicoot rat (*Bandicota bengalensis*), soft-furred rat (*Millardia meltada*), gerbil rat (*Tatera cuvieri, T. indica*), rat (*Rattus rattus*, *R. meltada*), short-tailed bandicoot rat (*Nesokia indica*) and five striped palm squirrel (*Funambulus pennanti*).

General characteristics of Rodents

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Length of life	:	12-18
Age at puberty	:	6-11
Breeding season	:	All round the year
Mating habit	:	Promiscuous
Oestrous cycle	:	4-6 days
Duration of oestrous	:	9-20 hours
Gestation period	:	21 days
First oestrous after pasturition	:	2-4 days

Feeding ecology: Rodents damage the field crops by gnawing, feeding, hoarding of grains and contamination of end product. A characteristic feature of rodents is their hoarding behaviour. Under laboratory conditions, *Tatera indica* continued hoarding of wheat and cereals until recovery of weight lost on previous diet (Kumari and Khan, 1979). While *R. rattus* is the most populous species found in both residential areas and fields, *B. bengalensis* is found most commonly in fields and vegetable gardens. The value of rodent contamination and spoilage loss is 20 percent higher than the value of the stored storage consumed. They contaminate stored goods with urinary feces, hair, and pathogens. Infected storage items often need to be declared unsuitable for human consumption. Rats consume 7% or 15% of their body weight daily as food. In particular, they impair the nutritional value and seed germination. A study on the behaviour of *B. bengalensis* during 2009-10 and 2010-11 reported that *B. bengalensis* displayed hoarding behaviour and collected food for the off-season @ 170.78 g per burrow. *B. bengalensis* dug burrows mean density of 20.33 ha-1 and 27.40 ha^{-1} in boro and sali rice, respectively. The average number of brood chambers observed was 1.41 with 2.97 food chambers and 5.47 surface openings (Gogoi and Borah, 2012). Also, the highest numbers of burrows were observed in bunds during the harvesting season while the rodents migrated to crop fields during ripening stage. The highest rodent populations are often observed in paddy fields. In the rice ecosystems of Assam, the damage caused by *B. bengalensis* showed an increase with crop growth and maximum damage rates of 4.14% and 5.78% cut tiller were reported during the ripening stage. Shiels *et al*. (2013) found that the dietary niche of co-existing rodent species differed greatly which may give an idea about the resource use and resource competition of these species. The rodents fed on an aggregate of arthropods and plant materials. The damage levels of rice and wheat crops due to *M. meltada* were 17.8% and 28.3%, respectively.

House mouse/field mouse (*Mus musculus*) — Norway rat/Brown rat (*Rattus norvegicus*)

Indian mole rat/lesser bandicoat rat (*Bandicota bengalensis*) — Black rat/house rat/bush rat (*Rattus rattus*)

Reproductive Ecology: Thousands of years of evolution have shaped the reproductive patterns of individuals in order to ensure survival of young ones for the continuation of one's species. The abundance of a species and its population density is highly influenced by its reproductive mechanisms. High reproductive potential of rodents is a fairly recognized fact. Historically, rodent population dynamics have been correlated to seed fall. The analysis of a global dataset comprising of the study of 156 rodent-seed pairs from 37 studies, taken from published material, the seed and rodent abundance positively correlated to each other. Additionally, the study found that the density dependence that influences the growth rates of rodent populations were higher than the relative importance of seed abundance (Liu *et al*., 2023). Over the decades, different hypothesis has been suggested to gather a more well-rounded information about the population dynamics and reproductive cycles of rodents. The population cycle of rodents is heavily influenced by the peaks in plant production, which may be linked to the accessibility to nutritious food during that period. Although originally the plant production was used to refer to the nutritious plant parts (like flowers and berries), it has now been extended to include other plant nutrient levels. Although food availability has a major influence on rats' reproductive cycle and potential, abiotic factors also play a big role. It is known that the rate at which rodents reproduce varies depending on their environment and climate. Rainfall was one abiotic element that significantly impacted female gestation and maturity. Prior research has demonstrated a connection between rodent productivity and rainfall. Each location has a different prevalence and accessibility of rodent species. *R. rattus* was the most common species in Mizoram, but *R. nitidus* was the most common species in Nagaland and Manipur. Despite being a major paddy pest in Mizoram, *B. bengalensis* did not significantly increase in population during the flowering season, or "Mautam," as it is known in the local dialect. During the decline of *Bambusa tulda*, large populations of *R. nitidus* and *R. r. brunneusculus* were observed in rice fields.

Conclusion

The most common and prolific vertebrate pest in agriculture is the rodent. It is a primary factor in field crop losses and storage grain losses, which annually cause enormous economic losses. Little is known about the pest's habitat, feeding habits, reproduction patterns, and population dynamics, despite its enormous economic impact. Rodents are one of the hardest pests to manage in agro-ecosystems because of a lack of information. The majority of current management techniques are chemo-centric and frequently fail to keep populations under control. Extensive research and studies are required to explore and gain more traction about the rodent population, especially in relation to agriculture to enable better management.

References

Cao, D., Pimentel, D. and Hart, K. (2002). Post harvest crop losses (insects and mites). In: Encyclopedia of Pest Management. (Ed.) Pimentel, D. Marcel Dekker, New York. pp. 723-730.

Shiels, A. B., Flores, C. A., Khamsing, A., Krushelnycky, P. D., Mosher, S. M. and Drake, D. R. (2013). Dietary niche differentiation among three species of invasive rodents (*Rattus rattus*, *R. exulans*, *Mus musculus*). *Biological invasions*, 15(5): 1037-1048.

Gogoi, P. P. and Borah, R. K. (2012). Burrowing behaviour of Lesser Bandicoot Rat, *Bandicota bengalensis* in rice ecosystem in Upper Brahmaputra valley Assam. *Annals of Plant Protection Sciences*, 20(2): 483-484.

Kumari, P. V. and Khan, J. A. (1979). Food hoarding by Indian gerbil, *Tatera indica indica* (Hardwicke). *Proceedings: Animal Sciences* 88: 131-135.

Labuschagne, L., Swanepoel, L. H., Taylor, P. J., Belmain, S. R. and Keith, M. (2016). Are avian predators effective biological control agents for rodent pest management in agricultural systems? *Biological Control*, 101: 94-102.

Legendre, L. F. (2003). Oral disorders of exotc rodents. *Veterinary Clinics: Exotc Animal Practce*, 6(3): 601-628.

Liu, R., Zhang, Y., Zhang, H., Cao, L. and Yan, C. (2023). A global evaluation of the associat-ions between long-term dynamics of seed falls and rodents. *Integrative Zoology*, 18(5): 831-842.

Witmer, G. W., Fall, M. W. and Fiedler, L. A. (1995). Rodent control, research and technology transfer. In: *Integrating People and Wildlife for a Sustainable Future*. (Eds.) Bissonette, J. and Krausman, P. Proceedings of the First International Wildlife Manage-ment Congress. Bethesda. The Wildlife Society, Bethesda, MD, USA. pp. 693-697.

Elango, K., Vijayalakshmi, G., Arunkumar, P., Sujithra, P. and Sobhana, E. (2022). Indian scenario of non-insect pests affecting agricultural crops - An overview. *Journal of Entomological Research*, 46(Suppl.): 1194-1204.

Safeguarding Beneficial Insects: Strategies and Innovations

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Introduction

The significance of agriculture in global food security cannot be overstated. Agriculture plays a pivotal role in providing sustenance for the world's rapidly growing population. Beyond being a mere means for producing food, agriculture provides livelihoods for billions and is the foundation of many economies. According to the Food and Agriculture Organization (FAO), nearly 2.5 billion people are involved in full-time or part time agricultural work, underlining the sector's importance in livelihood sustainability and economic development. Agricul-ture is confronted by a range of challenges that jeopardise its productivity and, by extension, global food security. Among these challenges are the perennial problems of pests and diseases, which can devastate crops and result in substantial yield losses. Pest-related issues could cause the loss of up to 40% of the world's potential food production each year (Heeb *et al*., 2019). Similarly, diseases like rice blast and wheat rot have the capacity to completely destroy fields, leaving vulnerable communities without food and possibly starving. Environmental stressors like harsh weather brought on by climate change exacerbate these difficulties. Temperature variations, floods, and droughts can all negatively affect crop quality and productivity. These issues' environmental implications also couldn't be disregarded. Chemical pesticides and fertilizers are frequently used excessively in modern agricultural techniques, which may have short-term advantages but may have long-term negative effects such as soil deterioration, water pollution, and biodiversity loss. Additionally, an over-reliance on monocultures weakens ecosystem resilience and makes agricultural systems more vulnerable to disease outbreaks. The combination of these issues emphasizes how urgently comprehen-sive and long-lasting plant protection measures are needed. The isolated strategy, which only focuses on one kind of crop or chemical management, is insufficient. A more comprehensive strategy of managing pests and diseases is provided by integrated plant protection strategies that incorporate chemical, biological, and cultural techniques. A sophisticated grasp of the ecology of diseases and pests as well as the environmental elements influencing them is necess-ary for these integrated methods. Big data applications in agriculture have the potential to completely transform decision-making processes

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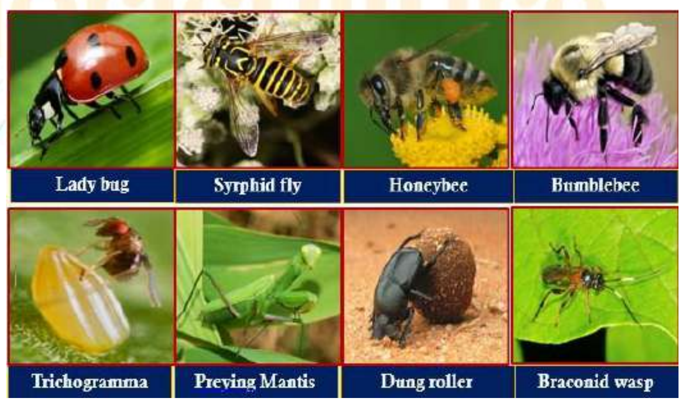
and provide more efficient and ecologically friendly crop protection solutions. Biological approaches to plant protection serve as one of the most promising avenues for sustainable agriculture. The increasing concerns over the environmental, health, and ecological implications of chemical pesticides have led to a surge in interest in alternative methods that are less harmful yet effective. Among these, biological approaches such as the use of natural predators, beneficial insects, and biopesticides stand out for their innovative take on leveraging nature's inherent systems for crop protection (Suckling and Sforza, 2014). Beneficial insects play a crucial role in maintaining ecosystem health and supporting agricultural productivity. These insects, including pollinators, natural pest controllers, and decomposers are integral to both the environment and human agriculture. Pollinators, such as bees and butterflies, are essential for the reproduction of many plants. Different beneficial insects are declining due to habitat loss, indiscriminate use of pesticides and competition from the invasive species.

Role of Beneficial Insects in Agriculture

Because of their numerous benefits that increase production, promote ecosystem health, and reduce the need for chemical pesticides, beneficial insects are important allies in sustainable agricultural systems. This section examines the vital functions performed by these helpful insects, which are divided into three categories: pollinators, decomposers, and biological control agents.

Biological Control Agents: Biological control, otherwise known as biocontrol, revolves around harnessing the natural enemies of pests to regulate their populations, thus reducing the dependency on harmful chemical pesticides. Predatory insects are essential players in managing pest populations. Lady beetles, lacewings, spiders, and praying mantises feed on a plethora of pests such as aphids, mites, caterpillars, and other small insects, mitigating potential crop damage. A further biological control mechanism is displayed by parasitoids. The developing larvae of these insects devour the host, ultimately leading to its death, after they lay their eggs in or on pest species. Since parasitoids, like some species of wasps and flies, are typically highly specialized and target particular pests, they are effective instruments for targeted pest control.

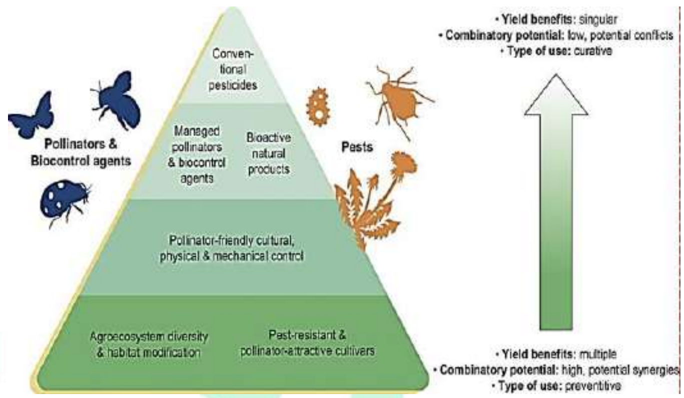


Pollinators: The service rendered by insect pollinators is indispensable in agriculture. Approximately 75% of globally significant crops benefit from animal pollination, with insects serving as the primary pollinators. One of the most well-known groups of pollinators is undoubtedly bees, including both wild and cultivated species like the honeybee. A wide variety of crops, such as almonds, apples, cherries, blueberries, cucumbers and different legumes are among those they help pollinate. Since almonds rely solely on honeybees for pollination, they are especially crucial to the crop's production.

Decomposers: Decomposer insects form the third category of beneficial insects, significantly contributing to soil health. They break down organic matter into simpler forms, allowing nutrient cycling back into the soil, ultimately enhancing soil fertility and promoting plant growth. Dung beetles are a classic example, playing a crucial role in nutrient cycling by decomposing livestock manure. Their activities not only recycle nutrients but also enhance soil structure and moisture-holding capacity, positively affecting plant growth.

Conservation Strategies for Beneficial Insects

Habitat preservation through protected areas: There are relatively few studies exploring insect representation in Protected Areas (PAs), especially when compared to the literature on other taxa (Chowdhury *et al*., 2022). It's crucial to integrate targeted conservation strategies, such as habitat restoration and monitoring programs, within PAs to effectively support and manage the diverse needs of beneficial insects, ensuring their continued presence and ecological functionality amidst climate-driven changes. Identify pollinators, decomposers and other beneficial insects and their habitat requirements such as food sources, breeding sites and shelter. Designing the protected area helps in supporting different insect species. This might include meadows, woodlands, wetlands and more. This may be followed by implementing conservation practices (habitat restoration: restore degraded habitats like planting native vegetation, creating ponds, or removing invasive species) within the protected area to make them suitable for insects. Set up some of the monitoring programs (surveys, trapping, and population assessments) to track insect populations and the effectiveness of conservation measures.



Habitat management and restoration: Generally speaking, wide, sunny spaces like meadows, grasslands, or shrubby areas make the best habitat for beneficial insects. Although the borders of mature forests may offer habitat for beneficial insects, the ecological needs of the majority of forest insects are different from those of typical beneficial insects found on farms. Sunlit spots with native grasses and wildflowers should be given priority in conservation planning in order to enhance the farm's insect habitat. Two popular methods for preserving different grass and wildflower plant populations on bigger areas are burning and mowing. If these management practices are used, they should be minimized as much as possible during the growing season so that insects can use pollen and nectar resources. If mowing, burning, or prescribed grazing are used to maintain beneficial insect habitat, harm can be reduced by dividing the on-farm habitat into separate management zones, each less than 30% of the total habitat.

Pesticide management: When both pesticides and natural enemies (predators and parasitoids) are employed in a crop, conflicts can be reduced by use of following selectivity principles of insecticides. The decrease in natural enemies due to the use of non-selective insecticides can disrupt the balance in ecosystems and lead to serious consequences for pest population dynamics. One of these consequences is known as resurgence and eruption of secondary pests (Gallo *et al*., 2002). Resurgence occurs when the populations of pests rebound after initially being suppressed by insecticides. This rebound can be even more significant than the original pest population, leading to outbreaks and increased damage to crops. Selectivity in the context of insecticide use can be classified into two main categories: ecological and physiological selectivity.

Climate change mitigation: Encouraging climate-resilient landscapes, preserving biological interconnectedness, and safeguarding important habitats are all part of supporting insect adaptation to climate change. It's critical to take into account environmental factors at both the macro (landscape level) and micro (micro-habitat level) levels when controlling insect populations and their habitats (Tougeron *et al*., 2022). Insect populations are impacted at the macro level by landscape elements such as vegetation cover, land use, and habitat connectivity. These elements can be upset by human endeavors like deforestation, urbanization, and agriculture. Agri-environmental plans, wildlife corridors or protected areas to sustain insect populations are examples of management tactics at this level. The suitability of habitat for insects is influenced at the micro-habitat level by elements like microclimates, vegetation structure, soil conditions, and resource availability. Implementing sustainable land practices, controlling water resources, or planting particular species can all improve the quality of microhabitats. Diverse microhabitats found in mountains and topographically difficult regions can aid in animals' adaptation to climate change. These diverse habitats include varying degrees of moisture, temperature, and cover, all of which can help animals that must adapt to changing climatic conditions. Animals can discover resources and situations that fit them thanks to this topographic diversity, which increases their survival and resilience as climatic patterns shift.

Public awareness and education: Beneficial insects are monitored and protected by communities through local conservation initiatives and citizen science projects. These programs promote stewardship and increase awareness. Campaigns for public education emphasize the value of beneficial insects and encourage actions that aid in their protection, like using fewer pesticides and planting plants that are conducive to pollinators. We should optimize the terrain by constructing networks of habitat corridors and stepping stones in order to ecologically enhance agricultural lands. In order to lessen the effects of climate change, this strategy increases insect diversity and offers climate refugia. Ecosystems are harmed by industrial fertilizers and excessive pesticide use. Protecting insects requires action at all levels, from global policies to individual choices. While biodiversity conservation is a systemic challenge, every person can make a difference through their actions. Raising awareness about the crucial role of insects in ecosystems is essential. Engaging the public with charismatic species and educating children about insects' importance in elementary school can help. Scientific advances must be paired with supportive policies, widespread awareness, and stakeholder education.

Conclusion

The rapidly evolving landscape of agriculture faces myriad challenges, including pests, diseases, and environmental factors that jeopardise global food security. The urgency of these challenges necessitates innovative plant protection strategies that are both effective and environmentally sustainable. The role of beneficial insects in sustainable agriculture is increasingly recognized and researched. These insects serve as natural pest control agents, pollinators, and recyclers of organic matter, significantly enhancing agricultural productivity and ecosystem resilience. Pollinators, natural pest controllers, and decomposers are examples of beneficial insects that are essential to agricultural and ecosystem health. However, invasive species, pesticides, climate change, and habitat loss pose challenges to them. A diversified strategy is needed for conservation, one that addresses climate change mitigation, pesticide control, and habitat preservation.

References

Balaska, V., Adamidou, Z., Vryzas, Z. and Gasteratos, A. (2023). Sustainable crop protection via robotics and artificial intelligence solutions. *Machines*, 11(8): 774.

Chowdhury, S., Alam, S., Labi, M. M., Khan, N., Rokonuzzaman, M., Biswas, D., ... and Fuller, R. A. (2022). Protected areas in South Asia: Status and prospects. *Science of The Total Environment*, 811: 152316.

Gallo, D., Nakano, O., Silveira-Neto, S., Carvalho, R. P. L., Baptista, G. C., Berti-Filho, E., Parra, J. R. P., Alves, S. B., Vendramin, J. D., Marchini, L. C., Lopes, J. R. S. and Omoto, C. (2002). *Manual de Entomologia Agrícola. Piracicaba, Fealq*, 6-9.

Heeb, L., Jenner, E. and Cock, M. J. (2019). Climate-smart pest management: building resilience of farms and landscapes to changing pest threats. *Journal of Pest Science*, 92(3): 951.

Suckling, D. M. and Sforza, R. F. H. (2014). What magnitude are observed non-target impacts from weed biocontrol?. *PloS one*, 9(1): e84847.

Tougeron, K., Couthouis, E., Marrec, R., Barascou, L., Baudry, J., Boussard, H., ... and Van Baaren, J. (2022). Multi-scale approach to biodiversity proxies of biological control service in European farmlands. *Science of the Total Environment*, 822: 153569.

Biodiversity conservation and Agroforestry

Vasundhara Gajanan Dhote, Mohd Anas and Dayanand Sai Painkra

Introduction

Habitat loss and environmental degradation caused by population growth, agricultural intensification, and deforestation are major contributors of loss of biodiversity and associated ecosystem functions (Culman *et al*., 2010). Even though modern agriculture is largely blamed for declining biodiversity, agricultural practices can conserve biodiversity when sustainable management practices are implemented to protect biodiversity. For example, in India, about half of all plant and animal species rely on agricultural settings. Thus, agricultural methods that offer food, shelter, improved environmental conditions and protection can preserve and enhance biodiversity. Stronger ties between agroforestry and biodiversity protection are produced by more sophisticated landscape-scale agroforestry techniques. Many farmers have intentionally included or maintained trees in their agricultural landscapes since the dawn of agriculture. The farmstead was able to thrive because of the numerous commodities and services that trees provide, including shade, shelter, energy, food, and fodder. Trees were crucial parts of the fallow vegetation on fields that were temporarily abandoned, especially in the tropics. Many trees were also kept on farm land for no particular reason as long as they did not impede the usage of the area (Jose, 2012). In some humid tropical regions trees have such a prominent place in farming systems that the difference between forest, old fallows, and extensively managed traditional tree crop plantations is not immediately evident to the untrained eye. However, despite the presence of trees in tropical farming systems since the very beginnings, knowledge about their use in farms and farmed landscapes has only relatively recently been consolidated into the science of agroforestry, and much still remains to be learned about the relationships between trees, crops and their environment. For the first roughly two decades of agroforestry research, agroforestry scientists were mostly concerned with the sustainable production of agricul tural goods, especially food, and this line of research has lost none of its relevance. However, over the last decade or so, scientists have also become interested in the environmental services that agroforestry practices may provide to local and even global society by maintaining watershed functions, retaining carbon in the plant-soil system, and, most recently, by supporting the conservation of biologic-

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Table 1: Traditional agroforestry systems

System Type	Description	Practices	Benefits
Silvopasture	Integration of trees with pasture and livestock	Grazing livestock under tree canopy, fodder tree planting	Improved forage quality, enhanced biodiversity, reduced soil erosion
Agrosilviculture	Combination of crops and trees	Alley cropping, shifting cultivation with trees, tree plantations in crop fields	Soil fertility improvement, reduced need for chemical fertilizers, enhanced crop yields
Agrosilvopasture	Integration of crops, trees, and livestock	Sequential cropping, multi layered cropping with animals, tree hedgerow systems	Diversified income, improved land use efficiency, soil conservation
Home Gardens	Small-scale agroforestry systems around homes	Mixed cropping, fruit trees with vegetables, medicinal plants	Food security, nutritional benefits, income generation from surplus
Taungya System	Combining forestry with seasonal agriculture	Growing annual crops during the early stages of forest establishment	Forest regeneration, temporary income from crops, reduced weeding costs
Forest Farming	Cultivation of high value crops under forest canopy	Non-timber forest products (e.g., mushrooms, herbs), shade tolerant crops	Diversification of forest products, enhanced forest health, sustainable income

al diversity. Schroth *et al*. (2004) identified and discussed three roles of agroforestry in biodiversity conservation on a landscape scale: the provision of supplementary, secondary habitat for species that tolerate a certain level of disturbance; the reduction of rates of conversion of natural habitat in certain cases; and the creation of a more benign and permeable matrix between habitat remnants compared with less tree-dominated land uses, which may support the integrity of these remnants and the conservation of their populations.

Evolution of Agroforestry Practices

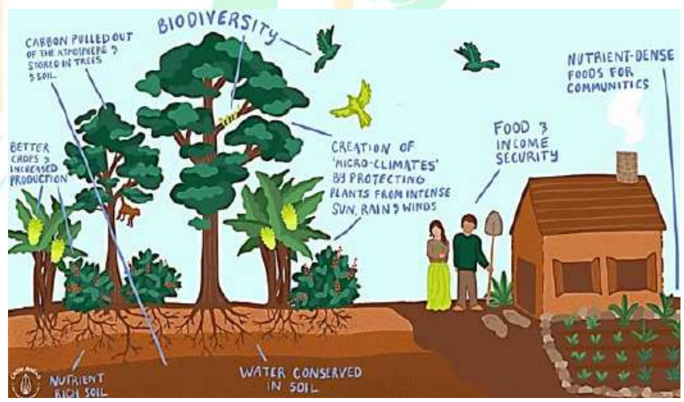
The evolution of agroforestry practices can be traced back to the increasing recognition of the limitations of conventional agricultural methods and the need for sustainable land management solutions. During the mid-20th century, the Green Revolution introduced high-yield crop varieties and chemical inputs that significantly boosted agricultural productivity but often led to soil degradation, water scarcity, and biodiversity loss (Chakwanda *et al*., 2024).

In response, researchers and practitioners began to explore agroforestry as a means to mitigate these negative impacts while sustaining agricultural productivity. In the 1970s, the establishment of the International Council for Research in Agroforestry (ICRAF), now known as the World Agroforestry Centre, marked a significant milestone in the development of agroforestry as a scientific discipline ICRAF's research emphasized the ecological and economic benefits of integrating trees into agricultural landscapes, leading to the development of various agroforestry models and practices. The publication of “Agroforestry: A Decade of Development” in 1987 further highlighted the potential of agroforestry to address global challenges such as food security, climate change, and biodiversity conservation. International policy frameworks and activities that acknowledge the significance of sustainable land management have aided in the development of agroforestry. Both the Convention on Biological Diversity (CBD) and the United Nations Convention to Combat Desertification (UNCCD) have supported agroforestry as a tactic to stop land degradation and advance biodiversity. Recent developments in sustainable agriculture and agroecology have further incorporated agroforestry techniques into management plans.

Agroforestry and Biodiversity Conservation

Role of Agroforestry in Habitat Creation: In order to create environments that support a diverse range of flora and wildlife, agroforestry is essential. Agroforestry systems replicate natural ecosystems by incorporating trees and shrubs with agricultural crops and livestock, creating a variety of habitats that are frequently more intricate and varied than those found in traditional agricultural landscapes. For birds, insects, animals, and other wildlife, trees and shrubs provide refuge, food, and nesting places. For example, adding native trees to agroforestry systems can greatly improve the availability and quality of habitat for nearby wildlife, supporting biodiversity conservation. Moreover, agroforestry practices such as hedgerows and riparian buffer strips create corridors that connect fragmented habitats, facilitating wildlife movement and gene flow across landscapes. This connectivity is crucial for maintaining viable populations of species that require large territories or specific habitat conditions. Agroforestry systems also contribute to the conservation of endangered species by providing alternative habitats in agricultural landscapes, thus reducing pressure on natural forests.

Enhancement of Genetic Diversity: Agroforestry enhances genetic diversity by incorporating a wide range of plant species, including trees, shrubs, and herbaceous plants, into agricultural systems. This diversity is crucial for the resilience and adaptability of ecosystems to environmental changes and stressors such as climate change, pests, and diseases. By maintaining and promoting traditional and indigenous tree species, agroforestry systems help conserve genetic resources that are often overlooked in conventional agriculture (Dawson *et al*., 2013). For example, traditional agroforestry systems in the tropics, such as home gardens and multi-strata systems, often include a diverse array of fruit trees, medicinal plants, and other useful species that have been selected and cultivated by local communities over generations.



Promotion of Species Richness: By establishing varied, multi-layered ecosystems that sustain a variety of plant and animal species, agroforestry systems increase species richness. Compared to monoculture systems, agroforestry systems have higher levels of biodiversity because of the structural complexity of their mix of trees, shrubs, and crops, which creates niches for various species. For instance, it has been demonstrated that agroforestry techniques like shade coffee and cacao systems in

Central and South America sustain high levels of biodiversity, including a variety of insect and bird species. Agroforestry systems not only promote above-ground biodiversity but also improve below-ground biodiversity by strengthening the structure and health of the soil. In agroforestry systems, the presence of trees and shrubs boosts the amount of organic matter added to the soil, encouraging the diversity and activity of soil microorganisms.

Water Regulation: Trees and shrubs in agroforestry systems play a vital role in regulating water cycles. Their deep root systems help improve water infiltration and reduce surface runoff, enhancing groundwater recharge and reducing the risk of flooding. Agroforestry practices such as riparian buffer strips protect water bodies by filtering sediments, nutrients, and pollutants from agricultural runoff, thereby improving water quality. Trees in agroforestry systems contribute to local and regional hydrological transpiration, cycles through which increases atmospheric moisture and can influence rainfall patterns. By enhancing water agroforestry regulation systems and provide quality, essential ecosystem services that support agricultural productivity and environmental health.

Conclusion

Agroforestry techniques address socio-economic, environmental, and technical issues while providing substantial promise for biodiversity protection and sustainable land management. Agroforestry systems improve habitat development, genetic variety, species richness, and ecosystem services like soil fertility, water regulation, carbon sequestration, and pest control by combining trees, crops, and livestock. Innovative methods and supportive policies can propel the widespread adoption of agroforestry despite adoption challenges such as socioeconomic limitations, policy gaps, and technical knowledge inadequacies. To overcome these obstacles and fully reap the rewards of agroforestry, ongoing research, development, and stakeholder collaboration are crucial.

References

Culman, S. W., Young-Mathews, A., Hollander, A. D., Ferris, H., Sánchez-Moreno, S., O'Geen, A. T. and Jackson, L. E. (2010). Biodiversity is associated with indicators of soil ecosystem functions over a landscape gradient of agricultural intensification. *Landscape Ecology*, 25(9): 1333-1348.

Jose, S. (2012). Agroforestry for conserving and enhancing biodiversity. *Agroforestry Systems*, 85(1): 1-8.

Schroth, G., da Fonseca, G. A., Harvey, C. A., Gascon, C., Vasconcelos, H. L. and Izac, A. M. N. (Eds.). (2013). Agroforestry and biodiversity conservation in tropical landscapes. Island press.

Chakwanda, M. A., Chenge, P. T., Baloyi, N., Tamburayi, G. L., Muchangana, M., Jarbah, P., ... and Sahoo, J. P. (2024). Green revolution: the catalyst for agricultural transformation. *Vigyan Varta: International Journal of E-Magazine Sci. Enthus*, 5: 294.

Dawson, I. K., Guariguata, M. R., Loo, J., Weber, J. C., Lengkeek, A., Bush, D., ... and Jamnadass, R. (2013). What is the relevance of smallholders' agroforestry systems for conserving tropical tree species and genetic diversity in circa situm, in situ and ex situ settings? A review. *Biodiversity and Conservation*, 22(2): 301-324.