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Innovative Technologies for Converting Organic Waste into Clean Energy

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Abstract

Organic waste is an underutilized resource with significant potential for clean energy generation. As global populations grow and urbanization accelerates, the amount of organic waste from agricultural, municipal, industrial, and domestic sources has reached critical levels. This accumulation not only poses environmental hazards but also represents a missed opportunity in the transition toward sustainable energy systems. Recent innovations in technology have paved the way for efficient and eco-friendly conversion of organic waste into various forms of renewable energy, including biogas, bioethanol, biodiesel, and electricity. This article explores the science, advancements, and real-world applications of such technologies, highlighting their impact on waste management, energy production, and climate mitigation.

The Need for Waste-to-Energy Innovations

The conversion of organic waste into clean energy has emerged as a pivotal solution to two of the most pressing global challenges: waste disposal and energy security. Traditional waste disposal methods such as landfilling and open burning contribute significantly to greenhouse gas emissions, particularly methane and carbon dioxide. These practices also result in land degradation, groundwater contamination, and health hazards. In contrast, waste-to-energy (WTE) technologies offer a dual benefit: reducing environmental pollution while generating renewable energy. Among the various types of WTE methods, biological and thermochemical processes have garnered the most attention.

Anaerobic Digestion and Composting Techniques : Anaerobic digestion (AD) is one of the most mature and widely adopted biological processes. In AD systems, microorganisms break down organic materials such as food scraps, animal manure, and sewage sludge in oxygen-free conditions. This process yields biogas, primarily composed of methane, which can be used directly for cooking and

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heating or upgraded into biomethane for injection into gas grids and vehicle fuel. The remaining digestate is a nutrient-rich by-product that can serve as an organic fertilizer, contributing to circular agriculture. Advanced AD technologies now feature improved reactor designs, better microbial consortia, and real-time monitoring systems that enhance efficiency and reduce energy input. Composting, though primarily aimed at producing soil enhancers, can also be integrated with energy systems by capturing the heat and gases produced during microbial decomposition. While not a direct electricity-generating method, it supports the broader ecosystem of organic waste utilization. Vermicomposting, in particular, has become a popular community-level solution, transforming household waste into valuable humus while minimizing methane emissions.

Algae-Based Bioenergy Systems: Another frontier in biological conversion is the use of algae. Algae can consume carbon dioxide and nutrients from wastewater to produce biomass, which is then processed into biodiesel or bioethanol. Algal systems are efficient in land use and can be operated in saline or wastewater, reducing the burden on freshwater resources. Recent innovations in photobioreactor design and genetic modification have made algal bioenergy systems more viable at commercial scales.

Thermochemical Conversion Technologies: On the thermochemical side, pyrolysis and gasification represent two cutting-edge technologies for converting organic waste into energy-dense products. Pyrolysis involves heating organic matter in the absence of oxygen, breaking it down into bio-oil, syngas, and biochar. These outputs can be used for electricity generation, heating, or even as chemical feedstocks. Gasification, by contrast, uses a limited supply of oxygen or steam to convert organic materials into syngas, a mixture of carbon monoxide and hydrogen. Syngas can be used in internal combustion engines or fuel cells, offering a cleaner alternative to fossil fuels. Both technologies have benefited from advancements in reactor design, temperature control, and catalyst use, enabling better scalability and efficiency.

Emerging Bioelectrochemical Technologies: One of the most exciting emerging technologies is microbial fuel cells (MFCs). These systems use bacteria to convert organic matter in wastewater into electricity. The microbes act as catalysts at the anode, breaking down the waste and releasing electrons, which then flow through an external circuit to generate current. Though still in developmental stages, MFCs hold promise for decentralized, low-energy wastewater treatment coupled with electricity production. Plasma arc gasification is a high-temperature technique that employs ionized gas (plasma) to break down organic waste into syngas and a vitrified slag. This technology can handle a wide variety of feedstocks and produces minimal emissions. Although it requires significant upfront investment, the high energy recovery rate and low environmental impact make it an attractive option for urban waste management. Bioelectrochemical systems, including microbial electrolysis cells (MEC

s), extend the concept of MFCs by using a small input of external voltage to drive the production of hydrogen or methane from organic waste. These systems offer a way to enhance the energy yield from waste while maintaining environmental benefits.

Smart Waste-to-Energy Management with AI and IoT: Artificial intelligence (AI) and the Internet of Things (IoT) are playing an increasing role in optimizing waste-to-energy systems. Smart sensors and real-time data analytics allow for precise monitoring of feedstock composition, temperature, and microbial activity, thereby enhancing process efficiency and reducing operational costs. Machine learning models can predict system behavior and suggest optimal operating conditions, contributing to more reliable and scalable waste-to-energy deployments.

Barriers and Policy Considerations: Despite the technological advancements, several challenges remain. Feedstock variability, high capital costs, and regulatory hurdles can hinder the adoption of innovative waste-to-energy systems. Public awareness and community participation are also critical for the success of decentralized systems. Integrated policy frameworks that incentivize renewable energy production, enforce waste segregation at source, and support research and development are essential for scaling these technologies.

Global Success Stories and Regional Initiatives: Globally, countries like Germany, Sweden, and South Korea have set benchmarks in organic waste-to-energy conversion through effective policy mechanisms and investment in infrastructure. In India, programs like the SATAT initiative aim to promote the use of compressed biogas as a vehicle fuel, leveraging agricultural and municipal waste. Pilot projects in Africa and Southeast Asia demonstrate how localized, low-cost technologies can empower rural communities with clean energy while improving sanitation and waste management.

Conclusion

In conclusion, the conversion of organic waste into clean energy represents a transformative opportunity to address environmental, economic, and energy challenges in an integrated manner. The continued evolution of technologies, combined with supportive policies and community engagement, can turn this vision into a global movement. By reimagining waste as a resource, societies can move closer to achieving circular economy goals, reducing reliance on fossil fuels, and mitigating the impacts of climate change.

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Application of Remote Sensing and GIS in Agricultural Data Collection and Analysis

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Abstract

Agriculture is central to global food security, yet it faces unprecedented challenges from population growth, climate change, and resource degradation. Effective decision-making requires accurate, timely, and large-scale agricultural data. Traditional surveys, while important, are often labour-intensive, time-consuming, and spatially limited. Remote sensing and Geographic Information Systems (GIS) provide powerful alternatives. Remote sensing delivers continuous, multi-temporal, and multispectral data on crops, soil, and water, while GIS enables integration, visualization, and spatial analysis. Together, they support precision farming, yield forecasting, drought monitoring, and land-use planning. This article reviews the principles, data sources, and methodologies of remote sensing and GIS in agricultural data collection and analysis. It highlights applications with global case studies, addresses current limitations, and outlines pathways for broader adoption. The findings confirm that integrating these technologies is essential for achieving sustainable agriculture and food security.

Introduction

Agriculture supplies food, raw materials, and livelihoods for billions of people. As the global population is projected to reach nearly 10 billion by 2050, the pressure on agricultural systems is intensifying. Farmers and policymakers require accurate information on crops, soils, water, and land to enhance productivity and sustainability. Traditional agricultural surveys rely on field visits, manual sampling, and census-based approaches. While effective at small scales, these methods are expensive, labour-intensive, and often outdated by the time data is processed. This creates gaps in timely decision-making.

Remote sensing and GIS have transformed agricultural monitoring. Remote sensing collects information about the Earth's surface using satellite, aerial, and drone sensors. GIS provides platforms to store, manage, analyse, and visualize spatial data. Together, these technologies generate timely and reliable insights on crop growth, yield, soil condition, water availability, and land use.

Principles of Remote Sensing and GIS

Remote Sensing

Remote sensing detects reflected or emitted radiation from the Earth's surface. It uses passive sensors, which capture natural energy such as sunlight, and active sensors, such as radar, which

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emit their own signals. Key aspects include:

Spectral resolution: the ability to measure specific wavelengths, essential for detecting vegetation and soil characteristics.

Spatial resolution: the size of the smallest object that can be detected, ranging from meters to centimetres.

Temporal resolution: how often a sensor revisits the same area, important for monitoring crop growth stages.

Vegetation indices such as the Normalized Difference Vegetation Index (NDVI) and Enhanced Vegetation Index (EVI) use reflectance data to assess plant health and biomass.

Geographic Information Systems (GIS)

GIS is a framework for managing spatial data. It allows users to input, store, analyse, and visualize geographically referenced information. For agriculture, GIS supports:

- ✓ Mapping soil fertility and water resources.
- ✓ Integrating multisource datasets, such as field surveys, climate data, and satellite images.
- ✓ Decision support through spatial modelling.

The combination of remote sensing and GIS enables real-time agricultural monitoring and targeted interventions.

Data Sources and Methodologies

Satellite Platforms

Landsat: 30 m resolution with long historical records, widely used for land cover change.

Sentinel-2 (ESA): 10 m resolution with frequent revisits, valuable for crop monitoring.

MODIS (NASA): moderate resolution but high temporal frequency, useful for drought monitoring.

Planet Scope: very high-resolution commercial imagery for precision farming.

UAVs and Drones

Unmanned Aerial Vehicles provide ultra-high-resolution imagery at the field level. They are increasingly used for detecting nutrient deficiencies, pest outbreaks, and soil variability.

Spectral Indices

NDVI: Assesses vegetation vigour.

SAVI: Corrects for soil brightness.

EVI: Improves sensitivity in dense vegetation.

GIS Techniques

- ✓ Overlay analysis for land suitability.
- ✓ Spatial interpolation for soil nutrient mapping.
- ✓ Hydrological modelling for irrigation planning.

Ground-Truthing

Remote sensing requires validation. Field measurements of biomass, soil moisture, or yield ensure the accuracy and reliability of models.

Applications in Agricultural Data Collection and Analysis

Crop Monitoring and Yield Estimation: Remote sensing provides continuous crop monitoring. NDVI time-series data reveal crop growth patterns, enabling yield prediction. In India, the FASAL program integrates satellite data with field surveys to forecast rice and wheat yields.

Precision Agriculture: GIS and remote sensing support site-specific management of inputs such as fertilizer, water, and pesticides. GPS-enabled machi-

nery uses prescription maps derived from spatial data, improving efficiency and reducing costs.

Soil and Water Resource Assessment: Microwave remote sensing measures soil moisture, vital for irrigation planning. GIS-based watershed modelling identifies suitable irrigation zones and monitors groundwater depletion.

Drought and Pest Monitoring: Satellite-derived indices such as the Vegetation Condition Index (VCI) provide early warning of drought stress. Remote sensing also detects pest-induced crop stress by monitoring spectral changes in leaves.

Land Use and Land Cover Change: Remote sensing tracks the conversion of forests to agricultural land, urban encroachment, and expansion of irrigated fields. GIS supports analysis of impacts on biodiversity, water resources, and sustainability.

Case Studies

India: Crop Yield Forecasting: The Indian Space Research Organisation (ISRO) uses IRS satellites for the FASAL program. By integrating satellite indices with meteorological and field data, the program delivers timely yield forecasts for food grains.

Africa: Drought Monitoring: The Famine Early Warning Systems Network (FEWS NET) uses MODIS and other datasets to monitor vegetation stress in sub-Saharan Africa. This supports humanitarian agencies in planning interventions.

United States: Precision Farming: In the Midwest, farmers employ UAV imagery to detect nitrogen deficiencies in maize. Prescription maps generated in GIS reduce fertilizer use while maintaining yields.

China: Land Use Change: Landsat data has been used extensively to track farmland expansion and urbanization in China. Results inform national land use policies and food security strategies.

Challenges and Limitations

Data accessibility: High-resolution imagery is costly, limiting use by smallholder farmers.

Technical capacity: Requires skilled personnel in image processing and GIS analysis.

Resolution limitations: Moderate-resolution imagery may not capture smallholder field variability.

Integration challenges: Adoption is slow where traditional practices dominate.

Policy gaps: Lack of institutional frameworks for data sharing and standardization.

The Way Forward

Open access data: Expansion of initiatives like Copernicus and Landsat that provide free imagery.

Capacity building: Training programs for extension workers, farmers, and policymakers.

Integration with emerging technologies: Combining remote sensing with IoT, drones, AI, and machine learning to enhance predictive analytics.

Mobile applications: Tools that deliver field-level advisories directly to farmers' phones.

Collaborative partnerships: Strengthening ties between governments, research institutions, and private companies.

Conclusion

Remote sensing and GIS have become indispensable in agricultural data collection and analysis. They provide scalable, accurate, and timely

information for crop monitoring, yield estimation, soil and water management, and disaster response. While challenges exist, improvements in open-access data, capacity development, and technological integration will accelerate adoption. These tools are critical for enhancing agricultural resilience, sustainability, and global food security.

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Global Trade Wars and their Impact on Farmers

Rayidi Krishnakanth

Abstract

Global trade wars disrupt agricultural supply chains, create price volatility, and increase uncertainty for farmers. Tariffs, retaliatory measures, and restrictions on key commodities alter market access and production costs, with small producers often bearing the burden. This article examines the impact of trade wars on global agriculture, focusing on India. Using data from soybean, cotton, palm oil, and fertilizer markets, it shows how Indian farmers face both opportunities and risks. While some sectors benefit from short-term market openings, others suffer from rising input costs and unstable prices. The paper recommends diversification, stronger domestic value chains, and risk management to build resilience.

Introduction

Agriculture is one of the most globally traded sectors. Cereals, oilseeds, cotton, meat, and dairy products move across continents, linking farmers in India with consumers in Africa, Asia, and Europe. Open trade allows surplus-producing countries to find markets while deficit regions secure food supplies. Trade wars disrupt this balance. They involve the imposition of tariffs, quotas, or sanctions, often as retaliatory measures between countries. While intended to protect domestic industries, trade wars usually destabilize markets. Agricultural products are often targeted for retaliation because they are politically sensitive and directly affect rural populations. Farmers are especially vulnerable. They face falling export demand when tariffs are imposed, and rising input costs when imports of fertilizers, feed, or machinery are restricted. In India, where agriculture provides livelihoods for more than 40 percent of the workforce, trade disruptions have wide-reaching consequences. This paper examines global trade wars, their effects on agriculture, and their specific impact on Indian farmers. Using case studies and real-world data, it analyses price volatility, supply chain shifts, and input cost increases. It also outlines strategies for building resilience in Indian agriculture.

Understanding Global Trade Wars

Trade wars arise when one country imposes tariffs or restrictions, prompting retaliatory measures by trading partners.

US-China trade conflict (2018-2020): The United States imposed tariffs on Chinese goods worth over USD 370 billion. China retaliated by imposing tariffs on soybeans, cotton, and dairy products from the US.

India-Malaysia palm oil dispute (2019): India restricted imports of refined palm oil from Malaysia following political tensions. Malaysia was India's

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second-largest supplier of palm oil.

Russia-Ukraine conflict (2022): Although not a tariff war, the conflict disrupted grain and fertilizer exports, creating global price shocks.

Trade wars reshape global agricultural flows. Major importers diversify suppliers, while exporters search for new markets. Farmers are caught in the middle of these realignments.

Agricultural Markets and Global Trade Dynamics

Agriculture represents about 10 percent of global trade (WTO, 2022). Global value chains link farmers with processors, traders, and consumers. A disruption in one link has cascading effects worldwide.

Soybeans: China accounts for over 60 percent of global soybean imports. The US, Brazil, and Argentina dominate exports.

Cotton: India, the US, and Brazil are leading exporters, while Bangladesh and Vietnam are major importers for textile industries.

Edible oils: India is the world's largest importer, buying over 60 percent of its domestic consumption from abroad. Palm oil from Indonesia and Malaysia is the most significant.

Fertilizers: India imports nearly 25 percent of its fertilizer demand, especially potash from Canada and urea from the Middle East.

Indian farmers thus operate within a globalized system. Their incomes depend not only on domestic demand but also on how trade wars shift international markets.

Impact of Trade Wars on Global Agriculture

Price Volatility

Agricultural commodities are highly price-sensitive.

- ✓ During the US-China soybean dispute, US exports to China fell by 75 percent, and global soybean prices dropped by 20 percent between 2018 and 2019 (FAO, 2020).
- ✓ Volatility creates uncertainty for farmers planning next season's crop.

Shifts in Supply Chains

- ✓ China increased soybean imports from Brazil, displacing US farmers.
- ✓ Indian exporters of oilseeds and cotton gained short-term opportunities, but these were unstable and highly competitive.

Rising Input Costs

- ✓ Tariffs on fertilizers, farm equipment and agrochemicals raised production costs world-wide.
- ✓ Indian farmers, already facing thin profit margins, were hit hard by fertilizer price hikes. In 2021-22, the average price of imported urea increased by more than 30 percent.

Impact on Indian Farmers

Soybean and Oilseed Sector

India grows soybeans domestically but remains dependent on imports of palm oil and other edible oils.

- ✓ In 2021, India imported nearly 13 million tonnes of palm oil, accounting for over 55 percent of its edible oil imports.
- ✓ Trade restrictions raise consumer prices, which

benefits some oilseed farmers but hurts consumers and processors.

Cotton and Textiles

India is the world's largest cotton producer and the second-largest exporter. Cotton exports fluctuate with global demand.

- ✓ In 2020, India exported about 10 million bales, but trade disruptions reduced demand, leading to a 12 percent fall in domestic prices.
- ✓ Textile tariffs in global markets indirectly reduce demand for raw cotton from Indian farmers.

Dairy and Livestock

India has the largest dairy industry globally, but exports are modest. Trade barriers on skimmed milk powder or butterfat reduce potential export opportunities. Farmers in cooperatives like Amul are directly affected by global tariff regimes.

Pulses and Cereals

India imports pulses such as lentils from Canada and Myanmar. Tariffs or restrictions raise domestic prices.

- ✓ In 2019, Canadian lentil imports fell due to Indian tariffs, pushing domestic lentil prices up by 10-15 percent.
- ✓ Consumers bear the burden, while farmers benefit unevenly depending on crop choices.

Fertilizers and Input Costs

India's fertilizer dependence makes it highly vulnerable.

- ✓ In 2021-22, the global fertilizer crisis, worsened by trade restrictions, increased the subsidy burden on the Indian government to nearly INR 1.4 trillion.
- ✓ Farmers faced higher prices for non-subsidized fertilizers, reducing profitability.

Case Studies with Data

US-China Trade War and Soybean Prices

- ✓ In 2017, China imported 36 million tonnes of soybeans from the US. By 2018, this had dropped by 75 percent due to tariffs.
- ✓ Global soybean prices fell from USD 10.5 per bushel in 2017 to below USD 8.5 in late 2018.
- ✓ Indian soybean farmers saw temporary gains as China sourced alternatives, but Brazilian dominance limited India's long-term benefit.

Palm Oil Restrictions and India

- ✓ In 2019, India restricted imports of refined palm oil from Malaysia after political disputes.
- ✓ Domestic edible oil prices rose by 15 percent within months.
- ✓ While oilseed farmers benefited, consumers faced inflation, and processors struggled with higher input costs.

Cotton Exports and Global Textile Competition

- ✓ India exports 30 percent of its cotton production. In 2020, the pandemic and trade disruptions reduced textile demand.
- ✓ Cotton prices in India dropped from INR 5,500 per quintal in 2019 to INR 4,800 in 2020.
- ✓ Farmers bore direct losses, despite being shielded partially by government procurement schemes.

Challenges and Limitations for Indian Agriculture

Dependence on imports: Over 60 percent of edible

oil and 25 percent of fertilizer requirements come from imports.

Low diversification: Farmers are concentrated in a few export crops like cotton and basmati rice, increasing vulnerability.

Infrastructure gaps: Poor storage and logistics reduce India's ability to take advantage of shifting trade flows.

Policy uncertainty: Frequent changes in export bans or tariffs create uncertainty for farmers and traders.

Limited risk management: Lack of accessible crop insurance and hedging mechanisms leaves farmers exposed to price volatility.

The WayForward

Diversify markets: India should expand agricultural exports to Africa, the Middle East, and Southeast Asia to reduce dependence on China and the EU.

Strengthen domestic value chains: Investments in food processing, cotton textiles, and oilseed crushing can reduce raw commodity dependence.

Promote self-reliance in inputs: Expanding domestic edible oil and fertilizer production will reduce vulnerability to global trade wars.

Farmer risk management: Develop hedging tools, crop insurance, and minimum support mechanisms to stabilize farmer incomes.

Policy coherence: Trade, agriculture, and industrial policies must be aligned to protect farmers during global shocks.

Conclusion

Global trade wars create instability in agricultural markets, reshaping supply chains and impacting farmer incomes. Indian farmers face both opportunities and challenges: while trade disruptions sometimes open temporary export markets, the longer-term effects are negative, with higher input costs and volatile commodity prices. Strengthening resilience through diversification, domestic value chains, and farmer support systems is essential. By adopting a coherent policy framework and investing in self-reliance, India can shield its farmers from the uncertainties of global trade conflicts.

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Machine Learning Approaches to Agricultural Data Analysis

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Abstract

Agriculture produces vast and diverse datasets from satellites, drones, soil sensors, weather stations, and market records. Traditional statistical methods cannot capture the nonlinear, dynamic, and high-dimensional patterns embedded in these datasets. Machine learning offers flexible approaches that can improve agricultural decision-making, enhance resource efficiency, and strengthen resilience to risks. This article reviews machine learning approaches applied to agricultural data analysis, focusing on supervised, unsupervised, deep learning, and reinforcement learning. It examines how these methods are used in yield prediction, disease and pest detection, soil and water management, climate risk analysis, and market optimization. The article also discusses challenges such as data quality, interpretability, scalability, and adoption barriers. The paper concludes with recommendations for integrating machine learning with emerging technologies, strengthening data infrastructure, and building institutional capacity. These approaches are critical for ensuring sustainable agricultural systems and global food security.

Introduction

Agriculture underpins global food security and rural livelihoods, but it faces mounting challenges. Rising population, climate change, land degradation, and water scarcity demand more efficient and resilient farming systems. By 2050, food production must increase by nearly 60 percent to meet projected demand. This requires innovative approaches to agricultural monitoring, planning, and management. Traditional statistical approaches have served agriculture well, but are limited in addressing complex, nonlinear relationships in agricultural systems. For instance, crop yield depends not only on soil quality but also on interactions between weather, management practices and pests.

These relationships vary across space and time. Statistical models often assume linearity and require simplified datasets, which may overlook hidden interactions. Machine learning provides a set of computational methods that can learn from large, complex datasets and make predictions or classifications without explicit programming. It is well-suited to agricultural data, which is high-dimensional, heterogeneous, and dynamic. By processing satellite imagery, soil sensor readings, genomic data, and climate records, machine learning models can identify hidden patterns, predict outcomes, and recommend decisions.

Machine Learning in the Context of Agriculture

Machine learning refers to algorithms that

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improve performance by learning from data. Unlike rule-based systems, machine learning adapts to new inputs and identifies patterns without explicit programming. Agricultural systems present ideal conditions for machine learning because they generate diverse datasets: satellite images, sensor readings, genomic sequences, and market trends. Machine learning can integrate these datasets to create predictive insights. Traditional statistical models are constrained by assumptions such as normal distributions or linear relationships. Machine learning models, in contrast, can model nonlinear, high-dimensional interactions. For instance, a random forest can predict crop yield by combining dozens of variables such as rainfall, soil nutrients, and temperature. Deep neural networks can analyse leaf images to detect diseases without manual feature extraction. The relevance of machine learning in agriculture also stems from technological advancements. Cheaper satellite imagery, widespread sensor deployment, and cloud computing make large-scale agricultural machine learning feasible. Integration with Internet of Things (IoT) devices and Geographic Information Systems (GIS) enhances decision support at both farm and policy levels.

Data Sources for Agricultural Machine Learning

Machine learning in agriculture depends on the quality and diversity of input data. Common sources include:

Remote Sensing: Satellite and UAV imagery provide multispectral and hyperspectral data for monitoring crops, soil, and water. Programs such as Landsat and Sentinel deliver free, high-quality imagery. Commercial platforms like Planet Scope and UAVs provide finer resolution for precision farming.

Field Sensors: Soil moisture probes, nutrient sensors, and automated weather stations generate continuous field-level data. These inputs are critical for irrigation scheduling, fertilizer management, and yield estimation.

Genomic and Phenotypic Data: Plant breeding generates vast datasets of genomic sequences and phenotypic traits. Machine learning accelerates the identification of favourable traits for breeding programs.

Market and Economic Data: Market prices, demand fluctuations, and supply chain data are increasingly integrated into predictive models for planning and logistics.

Climate and Environmental Data: Long-term meteorological datasets support climate risk assessment and adaptation strategies. Combining weather station data with satellite observations enhances model reliability.

These data sources, when integrated, enable machine learning models to provide comprehensive insights across the agricultural value chain.

Machine Learning Methods in Agricultural Data Analysis

Supervised Learning

Supervised learning uses labelled datasets to train models for prediction or classification. Algorithms include decision trees, random forests,

support vector machines (SVMs), and gradient boosting.

Applications: Yield forecasting, crop classification, and disease detection.

Example: Random forest models predicting maize yields in East Africa based on rainfall, soil data, and vegetation indices.

Unsupervised Learning

Unsupervised learning identifies patterns in unlabelled data. Clustering and dimensionality reduction are common approaches.

Applications: Identifying soil types, segmenting farmland, detecting cropping patterns.

Example: Kmeans clustering used to group fields by soil fertility potential.

Deep Learning

Deep learning applies multi-layer neural networks to analyse complex data. Convolutional Neural Networks (CNNs) excel at image recognition, while Recurrent Neural Networks (RNNs) and Long Short-Term Memory (LSTM) networks handle time-series data.

Applications: Disease detection from leaf images, yield prediction from sequential weather data.

Example: CNN models detecting leaf rust in wheat with over 90 percent accuracy.

Reinforcement Learning

Reinforcement learning optimizes actions by maximizing cumulative rewards through trial and error.

Applications: Adaptive irrigation management, autonomous farm machinery.

Example: RL algorithms scheduling irrigation to minimize water use while maintaining yields.

Applications in Agriculture

Crop Yield Prediction: Accurate yield forecasts support food security planning, market stability, and farm-level decision-making. Machine learning integrates soil, weather, and remote sensing data to predict yields. Studies show random forest and gradient boosting outperform traditional regression in yield forecasting.

Disease and Pest Detection: Pests and diseases cause major losses. Machine learning models trained on plant images can detect early symptoms. Smartphone-based apps now allow farmers to upload leaf images for automated diagnosis.

Soil and Water Management: Machine learning predicts soil organic carbon, nutrient availability, and water retention capacity. Predictive irrigation systems reduce water waste by integrating weather forecasts with soil moisture data. Reinforcement learning systems have demonstrated potential in adaptive irrigation scheduling.

Climate Risk Analysis: Machine learning supports early warning systems for droughts, floods, and heatwaves. LSTM networks are effective in predicting drought severity based on long-term weather sequences.

Market and Supply Chain Optimization: Agricultural supply chains are vulnerable to inefficiencies and volatility. Machine learning forecasts market prices, optimizes logistics, and reduces post-harvest losses. Models integrating weather data and historic-

al price trends provide more accurate forecasts.

Challenges and Limitations

Despite significant potential, several challenges hinder the adoption of machine learning in agriculture:

Data quality and availability: Agricultural datasets are often incomplete, inconsistent, or biased.

Model interpretability: Deep learning models act as black boxes, limiting trust among users.

Scalability: Models that perform well in research settings may fail in heterogeneous field conditions.

Technical barriers: Many farming communities lack expertise and infrastructure for advanced ML tools.

Ethical concerns: Issues of data ownership, privacy, and equitable access remain unresolved.

Future Directions

To realize the full potential of machine learning in agriculture, several steps are necessary:

Expand open-access datasets: More freely available, high-quality agricultural datasets will support innovation.

Develop interpretable models: Improving explain-ability builds trust and usability.

Capacity building: Training programs for farmers, extension workers, and policymakers are essential.

Integration with emerging technologies: Combining ML with IoT, drones, and blockchain creates holistic smart farming solutions.

Strengthen partnerships: Collaboration between governments, research institutions, and the private sector accelerates adoption.

Conclusion

Machine learning is reshaping agricultural data analysis by providing powerful tools to analyse complex datasets and deliver actionable insights. It enhances crop management, resource efficiency, and resilience to climate risks. However, widespread adoption requires overcoming barriers of data quality, interpretability, scalability, and capacity. Strategic investments in data infrastructure, model transparency, and farmer training will accelerate the integration of machine learning into agriculture. These technologies are central to meeting future food security and sustainability challenges.

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Major Loose Flowers of India

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Abstract

India is home to a rich diversity of flowers, many of which hold cultural, religious, and medicinal significance. Flowers such as marigold, jasmine, lotus, hibiscus, and tuberose are integral to daily life, especially in rituals, festivals, and offerings to deities. These flowers also offer a range of medicinal benefits, from anti-inflammatory properties to stress relief and digestive support. The use of loose flowers in garlands, decorations, and religious ceremonies highlights their importance in Indian traditions. This article explores the medicinal and cultural relevance of major loose flowers found across India, underscoring their value in both health and culture.

Introduction

India is home to a vast array of flowers that hold deep cultural, spiritual and ecological significance. Loose flowers, often used in religious rituals, festivals, and daily life, are an integral part of Indian traditions. Whether adorning temples, homes, or marketplaces, these flowers add beauty and positivity. In this article, we will explore some of the major loose flowers of India and their importance.

Marigold (Tagetes)

Medicinal Importance: Marigolds are rich in antioxidants and have anti-inflammatory properties. The flower is used to treat wounds, cuts, and insect bites. Marigold extracts are also used in skincare products for their healing and soothing effects, especially for dry skin and rashes.

Cultural and Religious Importance: Marigold is one of the most widely used flowers in Indian culture. It is believed to have a strong connection with Lord Vishnu and other deities. Marigold flowers are commonly seen in festivals like Diwali, Dussehra, and Holi. During weddings, they are used to create decorative garlands, symbolizing good fortune, protection, and the beginning of a new journey. Marigolds are also used to decorate homes and temples, as their bright colour is thought to attract positive energy and ward off evil spirits.

Jasmine (Jasminum)

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Medicinal Importance: Jasmine has a calming and soothing effect on the body, often used in aromatherapy for stress relief and anxiety. Its oil is used in massages and as a skin toner. Jasmine has also been used in traditional medicine to treat respiratory issues, headaches, and even to ease menstrual pain. The flower is believed to have antimicrobial properties.

Cultural and Religious Importance: Jasmine is revered in Hinduism and Buddhism for its purity and fragrance. It is often associated with Goddess Lakshmi (the goddess of wealth) and is used during her worship. In southern India, jasmine flowers are used in garlands, especially in temples and for religious ceremonies. The sweet fragrance is believed to be spiritually uplifting. In weddings, jasmine symbolizes love and devotion, and it is often used in bridal hair adornments.

Lotus (*Nelumbo nucifera*)

Medicinal Importance: The lotus plant has various medicinal uses. The seeds are used in Ayurveda to treat digestive problems, diarrhea, and insomnia. Lotus petals and leaves are also used to prepare soothing tonics for the skin, reducing inflammation and promoting healing. In some parts of India, lotus seeds are used in sweets for their cooling and calming properties.

Cultural and Religious Importance: The lotus is a symbol of purity and spiritual awakening in Indian culture, particularly in Hinduism and Buddhism. It represents the blossoming of the soul and is associated with gods like Vishnu and Brahma. The lotus is often depicted in art, with deities sitting on a lotus throne. It is used extensively in religious ceremonies and festivals, particularly in offerings to deities during pujas. The flower is also significant in Buddhist teachings, symbolizing the journey toward enlightenment.

Hibiscus (*Hibiscus rosa-sinensis*)

Medicinal Importance: Hibiscus flowers are rich in Vitamin C and are used to treat high blood pressure, high cholesterol, and promote liver health. The flower is also used in treating hair loss, as it is believed to promote hair growth and reduce dandruff. Hibiscus tea is popular for its cooling properties, especially in hot climate.

Cultural and Religious Importance: In Hinduism, the hibiscus flower is sacred to Goddess Kali, and it is commonly used in offerings to her. Its bold, vibrant colour symbolizes power, strength, and energy. The flower is also used in religious rituals and festivals, especially during Holi, as it is said to have a purifying effect. In some Indian cultures, hibiscus is believed to have protective qualities and is used in rituals to ward off evil.

Tuberose (*Polianthes tuberosa*)

Medicinal Importance: Tuberose is used in traditional medicine for its soothing effects on the nervous system. Its fragrance is believed to reduce anxiety and stress. The flowers are also used in some regions to treat headaches and insomnia. Tuberose oil is often used in massage therapies for its calming and healing effects.

Cultural and Religious Importance: Tuberose,

known for its intense fragrance, is considered a symbol of beauty and love in Indian culture. It is a staple in wedding decorations, particularly in the form of garlands. The flower is often used in festivals like Onam and Diwali, where its aroma is believed to bring joy and positive energy into homes. Tuberose is also seen as a symbol of purity and is often used in religious offerings.

Chrysanthemum (*Chrysanthemum indicum*)

Medicinal Importance: Chrysanthemum is used to treat various ailments, including colds, headaches, and fevers. The flower's extract is used to make herbal tea, which is believed to have cooling properties. Chrysanthemum tea is also known for its benefits to the eyes, improving vision and relieving eye strain.

Cultural and Religious Importance: Chrysanthemums are commonly used in India during the autumn festivals like Diwali. They are often used in temple decorations and in offerings to deities, symbolizing joy, peace, and longevity. The flower also has significance in Chinese culture, where it is associated with life and death, symbolizing the cycle of life.

Bougainvillea (*Bougainvillea spectabilis*)

Medicinal Importance: Bougainvillea flowers and leaves are used in traditional medicine to treat wounds, bruises, and cuts. In some regions, the leaves are used to make poultices for healing skin infections. The flowers are also used in some Ayurvedic treatments for their anti-inflammatory properties.

Cultural and Religious Importance: Bougainvillea is often used for ornamental purposes, brightening up gardens and homes. Its vibrant colours are symbolic of beauty and wealth. Bougainvillea is also associated with love and the arrival of spring in Indian culture. The flower is used in various decorations, especially during weddings and festivals, adding an element of celebration and colour to the surroundings.

Sunflower (*Helianthus annuus*)

Medicinal Importance: Sunflower seeds are a rich source of essential fatty acids, vitamins and minerals, promoting heart health and reducing cholesterol. The seeds are also used in traditional medicine to treat inflammation and reduce pain.

Cultural and Religious Importance: In India, sunflowers symbolize vitality, energy, and positivity. They are commonly used in celebrations and festivals, particularly in rural areas. Sunflowers are also linked to the sun, and are considered a symbol of growth, renewal, and good fortune.

Lilies (Lilium)

Medicinal Importance: Lilies are believed to have anti-inflammatory and antispasmodic properties. They are often used in herbal remedies to treat coughs, asthma, and other respiratory issues. The flowers are also used in skincare products for their soothing and moisturizing properties.

Cultural and Religious Importance: Lilies are symbolic of purity, innocence, and divine beauty in Indian culture. They are frequently offered in temples during worship, particularly in the service of

deities associated with purity like Lord Vishnu. Lilies also appear in religious art and are used in celebrations to mark auspicious occasions.

Plumeria (Frangipani)

Medicinal Importance: Plumeria flowers are used in traditional medicine for their calming and cooling effects on the body. The flowers are believed to have anti-inflammatory and analgesic properties, often used to treat headaches, joint pain, and skin conditions.

Cultural and Religious Importance: Plumeria is sacred in both Hinduism and Buddhism, symbolizing love, immortality, and divine beauty. It is used in religious ceremonies and rituals, often as an offering to gods and deities. The flower is also seen as a symbol of eternal life and is used in wedding garlands and temple decorations.

Loose Roses (*Rosa* spp.)

Medicinal Importance: Roses are well-known for their antioxidant and anti-inflammatory properties. Rose petals and rose water are used in Ayurveda and Unani medicine to treat digestive issues, sore throats, and skin irritations. Rose oil is valued in aroma-therapy for reducing stress and promoting emotional balance. The petals are also used to prepare cooling drinks (like rose sherbet) that help in managing body heat during summers.

Cultural and Religious Importance: Roses hold great cultural and religious value in India. They are offered in temples, especially to deities like Goddess Lakshmi and Lord Vishnu. Loose rose petals are used in making garlands, decorating pandals, and showering during rituals and weddings. Symbolizing love, devotion, and purity, roses are also integral to weddings, where they are used in garlands, bouquets, and hair adornments.

Crossandra (*Crossandra infundibuliformis*)

Medicinal Importance: Crossandra flowers are known in traditional medicine for their mild healing properties. They are sometimes used in herbal remedies to soothe scalp issues and as a natural hair conditioner. The plant is also believed to have anti-inflammatory qualities, though it is more commonly valued for its ornamental rather than medicinal use.

Cultural and Religious Importance: Crossandra, locally called *Kanakambaram* in South India, is widely used in religious ceremonies and temple offerings. Women traditionally wear crossandra flowers in their hair, especially during festivals and auspicious occasions. These flowers are considered symbols of beauty, prosperity, and joy, and their vibrant orange hue is thought to bring positive energy.

Conclusion

These flowers, ranging from the vibrant marigold to the fragrant jasmine, are not just beautiful additions to India's landscapes but also carry significant medicinal and cultural values. From their use in traditional medicine to their central role in religious rituals and festivals, these flowers are integral to the fabric of Indian life.

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Big Data and Artificial Intelligence in Agricultural Statistics: Opportunities and Challenges

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Abstract

The integration of Big Data and Artificial Intelligence (AI) into agricultural statistics offers transformative opportunities for enhancing productivity, sustainability, and resilience in farming systems. These technologies enable precise monitoring, predictive analytics, and optimized resource management. However, their adoption faces challenges such as data quality issues, infrastructure limitations, and the need for skilled personnel. This article explores the potential benefits and obstacles associated with the application of Big Data and AI in agricultural statistics, emphasizing the importance of addressing these challenges to fully realize their advantages.

Introduction

Agriculture, a cornerstone of global food security and economic stability, is undergoing a significant transformation through the integration of digital technologies. Big Data and Artificial Intelligence (AI) are at the forefront of this revolution, offering unprecedented capabilities in data collection, analysis, and decision-making. These advancements promise to enhance agricultural productivity, sustainability, and resilience. However, the implementation of these technologies also presents a range of challenges that must be addressed to ensure their effective utilization.

The Role of Big Data and AI in Agricultural Statistics

Big Data in Agriculture: Big Data refers to the vast volumes of structured and unstructured data generated from various sources such as satellite imagery, sensor networks, weather stations and market transactions. In agriculture, this data encompasses information on soil health, crop performance, climatic conditions, and market trends. The analysis of Big Data allows for the identification of patterns and trends that can inform decision-making processes.

Artificial Intelligence in Agriculture: AI involves the use of algorithms and machine learning models to analyze data, make predictions, and automate tasks. In agriculture, AI applications include crop disease detection, yield prediction, precision irrigation, and supply chain optimization. By processing large datasets, AI can provide insights that enhance efficiency and productivity in farming operations.

Opportunities Presented by Big Data and AI

Enhanced Decision-Making: The integration of Big Data and AI enables farmers and policymakers to make informed decisions based on real-time data and

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predictive analytics. For instance, AI models can forecast crop yields, allowing for better planning and resource allocation. Similarly, Big Data analytics can identify market trends, helping farmers to align production with demand.

Improved Resource Management: AI-driven precision agriculture techniques optimize the use of resources such as water, fertilizers, and pesticides. By analyzing soil moisture levels and weather patterns, AI systems can recommend optimal irrigation schedules, reducing water wastage. This not only conserves resources but also minimizes environmental impact.

Early Detection of Pests and Diseases: AI-powered image recognition and sensor technologies can detect early signs of pests and diseases in crops. By identifying these threats promptly, farmers can take targeted actions to mitigate damage, reducing the need for broad-spectrum pesticide applications and enhancing crop health.

Supply Chain Optimization: Big Data analytics facilitate the optimization of agricultural supply chains by providing insights into production, transportation, and market dynamics. This leads to reduced food waste, improved logistics, and better alignment of supply with consumer demand.

Challenges in Implementing Big Data and AI in Agriculture

Data Quality and Accessibility: The effectiveness of Big Data and AI relies heavily on the quality and accessibility of data. In many regions, especially in developing countries, data collection infrastructure is inadequate, leading to incomplete or inaccurate datasets. Additionally, data silos and lack of standardization hinder the integration and sharing of information.

Infrastructure Limitations: Implementing AI and Big Data solutions requires robust technological infrastructure, including high-speed internet, data storage facilities, and computational resources. In rural areas, these infrastructure components are often lacking, posing significant barriers to the adoption of digital agriculture technologies.

Skill Gaps: The deployment of AI and Big Data in agriculture necessitates a workforce with specialized skills in data science, machine learning, and agronomy. There is a shortage of professionals with the requisite expertise, and existing training programs may not be accessible to all farmers, particularly those in remote areas.

Privacy and Ethical Concerns: The collection and analysis of large volumes of data raise issues related to data privacy and ethics. Farmers may be reluctant to share data due to concerns over ownership, security, and potential misuse. Establishing clear data governance frameworks is essential to address these concerns and build trust among stakeholders.

Case Studies and Applications

India: Satellite Data for Crop Management: In India, the integration of satellite data with AI has led to significant improvements in crop management. For example, Indian farmer Lokeswara Reddy utilized satellite data from Cropin, facilitated by Syngenta to optimize sowing times, manage irrigate-

ion and forecast weather patterns. As a result, his net profit per acre increased from 5,000-10,000 rupees to 20,000 rupees, demonstrating the potential of digital agriculture in enhancing farm income.

IIIT-Allahabad: Real-Time Crop Disease Detection: Researchers at the Indian Institute of Information Technology (IIIT) Allahabad developed an AI-based technology for real-time crop disease detection. The system uses a combination of AI, Internet of Things (IoT), deep learning, and federated learning to analyze crop health through leaf images and environmental data. With a detection success rate of up to 97.25%, this innovation offers a breakthrough for Indian agriculture, particularly in remote areas.

Strategies for Overcoming Challenges

Enhancing Data Infrastructure: Investing in data collection infrastructure, such as weather stations, soil sensors, and satellite imaging, is crucial for obtaining high-quality data. Governments and private sector entities should collaborate to build and maintain these infrastructures, ensuring data is accurate, timely, and accessible.

Capacity Building and Training: Developing training programs that equip farmers and agricultural professionals with skills in data analysis and AI is essential. These programs should be tailored to the local context and delivered in accessible formats, such as mobile applications and community workshops.

Establishing Data Governance Frameworks: Creating clear policies regarding data ownership, privacy, and sharing can address ethical concerns and build trust among stakeholders. These frameworks should be developed collaboratively, involving farmers, policymakers, and technology providers.

Promoting Public-Private Partnerships: Collaboration between governments, research institutions, and private companies can facilitate the development and deployment of AI and Big Data solutions. Public-private partnerships can pool resources, share knowledge, and scale successful initiatives.

Conclusion

The integration of Big Data and AI into agricultural statistics holds immense potential for transforming farming practices, enhancing productivity and ensuring food security. While challenges such as data quality, infrastructure limitations, and skill gaps exist, they are not insurmountable. Through concerted efforts in infrastructure development, capacity building, and policy formulation, these challenges can be addressed. By harnessing the power of digital technologies, agriculture can move towards a more sustainable and resilient future.

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Nourishment Security in an Evolving World Integrating Traditional Knowledge with Contemporary Science

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Introduction

Nourishment security is a pressing challenge in an evolving world where over 735 million people globally faced hunger in 2022 (FAO, 2023). In India, despite being the second-largest food producer, over 74% of the population cannot afford healthy diets, and 16.6% remain undernourished (FAO, SOFI 2023). While modern science advances high-yield crops and biotechnology, traditional knowledge safeguards biodiversity, resilient seeds, and sustainable farming. Integrating indigenous wisdom with contemporary science can address malnutrition, climate stress, and resource depletion. This fusion offers a pathway to resilient food systems ensuring availability, access, and nutrition for current and future generations.

Learning from the Past: Ancient and Indigenous Farming Practices

Throughout history, indigenous communities and ancient civilizations have developed sophist-icated farming systems tailored to their environ-ments. These practices are rooted in a deep understanding of local ecosystems and natural cycles, often emphasizing sustainability and biodiversity.

Key Traditional Techniques and their Benefits

Crop Rotation and Polyculture: Rotating crops like legumes and cereals helps restore soil nutrients naturally, reducing dependence on chemical fertilizers. Polyculture systems like the “milpa” in Central America, which combines maize, beans, and squash, promote mutual benefit among plants, control pests naturally, and enhance soil fertility through nitrogen fixation.

Seed Saving and Preservation: Farmers select and save seeds from resilient plants adapted to local conditions, ensuring genetic diversity and resilience against pests and diseases.

Techniques such as rainwater harvesting, contour bunding, and zai pits improve water retention and availability during dry seasons.

Agroforestry: Integrating trees into farming landscapes provides shade, reduces wind erosion, enhances biodiversity, sequesters carbon, and offers additional products like fruits, nuts, and medicinal herbs. Composting and mulching improve soil health, reduce reliance on chemical inputs, and recycle nutrients efficiently.

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Impact and Evidence: Research by organizations like the World Agroforestry Centre (ICRAF) shows that traditional practices, when supported by scientific validation, can significantly boost yields, improve soil health, and increase resilience against climate variability.

Case Study: In Ethiopia's Tigray region, farmers practicing traditional terracing and soil conservation techniques have maintained or increased crop yields despite frequent droughts. These practices prevent soil erosion and conserve moisture, proving their resilience and ecological soundness.

Harnessing New Technologies for Better Farming

Modern science offers tools that can enhance, complement, and scale traditional practices making agriculture more efficient, sustainable, and climate-resilient.

Key Innovations: Crops like drought-tolerant maize and pest-resistant cotton can withstand environmental stresses, reduce pesticide use, and increase yields. GPS-guided machinery and drone technology enable precise application of inputs, minimizing waste and environmental impact. Soil sensors and satellite imagery help monitor crop health, soil moisture, and nutrient levels in real time.

Climate-Resilient Crop Breeding: Developing varieties that tolerate salinity, floods, droughts, and high temperatures through advanced breeding and biotechnological methods. Mobile apps and data platforms provide farmers with timely weather updates, enabling better planning and risk management. In India, the adoption of drought tolerant wheat and rice varieties has demonstrated increased productivity during irregular rainfall seasons. Similarly, precision irrigation projects in Israel have optimized water use, saving billions of liters annually.

Working Together: Merging Traditional Knowledge with Modern Science:

To fully realize the potential of integrated approaches, research institutions and development organizations are pioneering programs that combine ancestral wisdom with scientific validation and technological innovation.

Integrated Strategies: Agroforestry and Clavipectoral Systems: Planting trees with crops and livestock improves land use, captures carbon, and supports biodiversity. Using modern rainwater collection along with traditional methods helps farmers cope with drought. Growing different crops and developing climate-resistant types reduce risks from pests and weather shocks. Combining composting with scientific soil testing and biofertilizers keeps soils healthy sustainably.

Success Stories: In Kenya, agroforestry increased yields and income, while in Bangladesh, combining water conservation with drought-resistant crops improved food security.

Challenges and Solutions: Many barriers exist, like lack of validation, cultural differences, limited resources, and weak policies. Solutions include involving farmers in research, providing training,

offering financial support, and protecting traditional knowledge through laws.

Building a Better Future: Collaboration among governments, scientists, farmers, and consumers is key. We need resilient, diverse farms, eco-friendly practices, and shared knowledge worldwide to ensure food security and environmental health.

Practical Actions: Students should learn and promote sustainable farming. Farmers can try combining traditional and new techniques. Policymakers need to support sustainable practices and protect indigenous knowledge. Researchers should work with communities to develop local solutions.

Final Thought: By blending ancient wisdom with modern science, we can create sustainable food systems that nourish people and protect our planet for future generations.

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Digital Agriculture: How E-Commerce is Transforming Farm-to-Table Connections

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Abstract

This article explores how online commerce is reshaping agriculture and the supply chains that connect farms to consumers. The rise of digital platforms is cutting down the role of middlemen, improving pricing transparency, and allowing farmers to reach both domestic and global markets more directly. By drawing lessons from initiatives like India's eNAM and China's Pinduoduo, it becomes clear that when technology is paired with strong policies and infrastructure, it can transform marketing systems in agriculture. The paper also highlights challenges such as poor connectivity, lack of digital literacy, and infrastructure barriers, while offering strategies to create more inclusive and sustainable trade ecosystems.

Introduction

Agriculture today is undergoing major changes as digital technologies simplify how goods move from farmers to consumers. In the past, the supply chain was lengthy and inefficient, relying heavily on middlemen. E-commerce has emerged as a new force that connects producers directly with urban buyers, cutting delays and improving efficiency.

The Digital Transformation of Agriculture

Agriculture has traditionally depended on manual labor and informal, fragmented markets. With the expansion of digital tools and internet access, this situation is changing. Farmers can now promote and sell their crops directly to end users, traders, and institutions. This has created competitive and transparent markets where farmers receive fairer returns and quality standards improve.

Understanding Agri-Marketing in the Digital Era

Agri-marketing covers the full journey of produce from storage and packaging to transport and retail. Digital tools such as apps and online marketplaces are making this chain more efficient. With increasing smartphone use, farmers now have greater access to price information, market trends, and new customers.

E-Commerce in Agriculture: Key Benefits

Online platforms benefit both farmers and consumers in several ways:

- ✓ They cut out unnecessary intermediaries, ensuring farmers get a better share of the price.
- ✓ Farmers can reach markets beyond their local region, sometimes internationally.
- ✓ Consumers receive fresh produce, fair pricing, and improved traceability.
- ✓ Data analytics allow farmers to make smarter decisions about what crops to grow and when to

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Noteworthy Initiatives and Success Stories

A number of initiatives demonstrate the role of digital agriculture:

- ✓ Ninjacart (India) links farmers to retailers and restaurants with fast, AI-enabled supply chains.
- ✓ AgroStar provides farmers with input supplies and advisory services through mobile apps in regional languages.
- ✓ TaniHub (Indonesia) runs a farm-to-business model, handling sales, logistics, and payments.
- ✓ Sunbasket (USA) sources sustainably grown produce to deliver organic meal kits to consumers.

Persistent Challenges in Digital Agri-Marketing

Adoption of digital agriculture still faces obstacles:

- ✓ Low digital skills among farmers.
- ✓ Poor internet coverage in rural areas.
- ✓ Inadequate cold storage and transport facilities.
- ✓ Trust issues and reluctance to rely on digital systems.

Building a Smarter, More Inclusive Agri-Commerce System

Strengthening digital agriculture requires:

- ✓ Digital literacy and training programs for farmers.
- ✓ Apps and platforms in local languages to boost accessibility.
- ✓ Stronger rural logistics and cold storage networks.
- ✓ Supportive policies and subsidies.
- ✓ Promotion of Farmer Producer Organizations (FPOs) to improve collective bargaining and digital participation.

Global Case Studies: E-Commerce Driving Agricultural Transformation

Several countries showcase how digital tools can transform farming:

- ✓ eNAM in India integrates over 1,000 markets to improve transparency and competition.
- ✓ Pinduoduo in China applies a group-buying model, lowering costs and expanding market access.
- ✓ OpenFarm in South Korea uses IoT and big data to support real-time decision-making and direct access to markets.

These examples underline the value of tailoring digital solutions to specific local needs.

Conclusion: The Future is Digital and Inclusive

Digital platforms are redefining the agricultural trade system, bringing farmers and consumers closer together. They help secure farmer incomes while delivering fresher and more reliable food to buyers. To ensure long-term success, it is essential to close gaps in connectivity, skills, and infrastructure, ensuring that digital agriculture is accessible and fair for all.

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Role of GIS and Remote Sensing in Forestry

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Abstract

Forests are essential for biodiversity, climate regulation, and human livelihoods, yet they face rising threats from deforestation, degradation, and climate change. Geographic Information Systems (GIS) and remote sensing have emerged as critical tools in forestry by providing accurate, timely, and large-scale data for research and management. GIS supports spatial analysis, forest planning, and resource modeling, while remote sensing enables continuous monitoring of forest cover, biomass, carbon stocks, and fire events. Integrated applications improve decision-making for sustainable forest management and conservation. Recent advances in drones, machine learning, and cloud-based platforms further enhance efficiency and accessibility. This article reviews the applications, challenges, and future directions of GIS and remote sensing in forestry, emphasizing their role in addressing global sustainability goals.

Introduction

Forests cover about 31 percent of the world's land area, making them one of the most important ecosystems on Earth. They act as carbon sinks, regulate the hydrological cycle, conserve soil, and provide habitat for more than 80 percent of terrestrial species. Forests also sustain the livelihoods of an estimated 1.6 billion people worldwide through timber, non-timber products, and ecosystem services. Despite their importance, forests face intense pressure. Global deforestation continues at a rate of approximately 10 million hectares per year, with tropical regions experiencing the highest losses. Drivers include agricultural expansion, infrastructure development, logging, mining, and urban growth. These changes disrupt biodiversity, accelerate greenhouse gas emissions, and weaken the capacity of ecosystems to provide services essential for human well-being. Effective forest management depends on timely and accurate information about forest extent, condition, and dynamics. Traditional approaches, such as ground-based forest inventories,

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yield detailed data but are resource-intensive, time-consuming, and limited to local or regional scales. They often cannot meet the requirements of national-level reporting, global climate commitments, or rapid response to emerging threats like fires or illegal logging.

Advances in geospatial technologies provide a solution. Geographic Information Systems (GIS) and remote sensing offer scalable, efficient, and repeatable methods for collecting and analyzing forest data. Remote sensing allows continuous monitoring through satellite, aerial, or drone imagery, producing data on forest cover, structure, and change over time. GIS enables integration of these datasets with other spatial information, such as topography, soils, climate, and socio-economic data, to support informed decision-making. The use of GIS and remote sensing has grown rapidly in the last three decades. Applications now extend beyond basic mapping to include biomass estimation, carbon accounting, biodiversity monitoring, and early warning systems for forest degradation and fire. At the policy level, they support international frameworks such as REDD+ (Reducing Emissions from Deforestation and Forest Degradation), the Sustainable Development Goals, and national climate strategies.

Understanding GIS and Remote Sensing: GIS is a system for capturing, storing, analysing, and visualizing spatial data. It helps integrate forest data with topography, hydrology, and socio-economic layers. Remote sensing uses sensors on satellites or aircraft to capture earth surface information. Optical, radar, and LiDAR sensors provide multi-resolution data. GIS and remote sensing complement each other by linking spatial analysis with continuous earth observation.

Applications of GIS in Forestry

Forest inventory and mapping: GIS supports accurate delineation of forest boundaries, species distribution, and age classes.

Spatial modeling: Predictive models help simulate forest growth, wildfire risk, and pest outbreaks.

Planning: GIS aids in identifying suitable areas for afforestation, conservation zones, and sustainable harvesting.

Applications of Remote Sensing in Forestry

Change detection: Time-series satellite imagery tracks deforestation, afforestation, and degradation. Landsat archives have been critical for long-term studies.

Biomass and carbon stocks: Remote sensing combined with ground data supports REDD+ projects by quantifying carbon sequestration.

Fire monitoring: MODIS and VIIRS sensors detect active fires in near real time.

Biodiversity: Remote sensing provides habitat maps for endangered species and supports landscape connectivity studies.

Integrated Use of GIS and Remote Sensing: Integration improves accuracy and usability. Case studies show success in:

Tropical forests: Monitoring illegal logging in the Amazon.

Temperate forests: Sustainable harvest planning in Europe.

Boreal forests: Fire risk modelling in Canada and Russia.

Decision support systems like FAO's SEPAL combine these technologies for global forest monitoring.

Advancements and Emerging Technologies

Drones/UAVs: Provide high-resolution imagery for small-scale forest studies.

AI/ML: Automates image classification and enhances land cover mapping.

Cloud computing: Google Earth Engine allows large-scale analysis of petabyte-scale datasets. These advancements reduce costs and make near-real-time monitoring possible.

Limitations and Challenges

Data limitations: Cloud cover, sensor resolution, and temporal gaps affect accuracy.

Technical constraints: Processing requires expertise and infrastructure.

Financial barriers: High costs of LiDAR or UAV-based surveys.

Capacity building: Many forest-dependent countries lack trained personnel.

The Way Forward

- ✓ Encourage partnerships among governments, research institutions, and communities.
- ✓ Integrate indigenous knowledge with geospatial monitoring.
- ✓ Promote open access to satellite data and GIS tools.
- ✓ Align GIS and remote sensing applications with Sustainable Development Goals, especially climate action and biodiversity conservation.

Conclusion

GIS and remote sensing have changed the way forests are studied, monitored, and managed. They provide accurate data on forest cover, land use, and ecosystem services that were once impossible to obtain at scale. These technologies allow researchers and managers to track deforestation, assess forest health, and plan for restoration in a cost-effective and timely manner. Their role is central to addressing climate change. Remote sensing helps quantify carbon stocks and emissions, which supports global mechanisms such as REDD+. GIS-based models inform climate adaptation strategies by predicting forest responses to temperature, rainfall shifts, and extreme events. Together, they form the backbone of scientific approaches to climate mitigation and resilience planning. They also advance biodiversity conservation. High-resolution imagery helps identify critical habitats, track migration corridors, and design protected areas. GIS supports spatial prioritization by integrating ecological, social, and economic factors into conservation planning. This ensures that biodiversity protection aligns with human needs and policy frameworks.

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Resilient by Nature: Breeding Crops for an Uncertain Future

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Abstract

Climate change is creating a serious and never-before-seen threat to global food security, making fast and smart changes in farming very important. As the FAO says, "Without adaptation, climate change will reduce agricultural productivity in many regions," showing how important it is to find strong and lasting solutions. This article looks at how advanced plant breeding, especially creating hybrids and varieties that can handle tough climates, is becoming a key part of growing food in a sustainable way. By using the power of genetic diversity and modern tools like genomic selection and gene editing, scientists are creating crops that can survive extreme weather, including drought, heat, floods, and salty soils. The article talks about how Hybrid Rice Nutrient Uptake Helps Climate-Resilient Farming and the important traits these crops need, gives examples of successful changes already helping farmers, and looks at both the challenges and opportunities in building farming systems that can handle climate change. As a CGIAR report says, "The future of food depends on how well science can keep pace with a changing climate." In the end, this article shows that science and innovation are not optional; they are necessary to protect food supplies as the environment changes. It calls for people and countries to work together to build a secure and climate-resilient future for everyone.

Introduction

The world is facing a serious problem: climate change is happening now, and farming is one of the most affected areas. Rainfall has become unpredictable, temperatures are rising, and extreme weather like floods and droughts are happening more often. These changes are making it harder to grow food. Crop harvests are less stable, the quality of important foods is going down, and many farmers are struggling to make a living. To feed more and more people in this changing world, we need smart and new ways of farming not just the old methods. This is where plant breeders play an important role. They use science and technology to create new types of crops that can survive tough weather and changing conditions. Their work is helping to protect our food supply now and for the future.

What is Climate-Resilient Agriculture?

Climate-resilient agriculture goes beyond simply producing food; it focuses on growing food that can endure the challenges brought on by a changing climate. It involves developing crop and

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livestock varieties that can tolerate environmental stresses such as drought, heat, floods, and poor soil conditions, while still maintaining good levels of productivity and contributing to stable food supplies.

Achieving this requires a proactive and multi-dimensional approach. It means adopting strategies that build resilience into the very foundation of our agricultural systems, including improved water management, healthier soils, and sustainable land use practices. Among these, the development of stronger, climate-smart hybrids and varieties stands out as a key element. These resilient crops form the backbone of climate-resilient agriculture, helping farms continue to thrive even when growing conditions become harsh.

The Power of Hybrids and Varieties: Using Nature to Grow Better Crops

For thousands of years, humans chose the best plants to grow, starting the journey of farming. Today, plant breeding blends this traditional knowledge with modern science. A big part of this is using genetic diversity traits found in wild plants and old crop varieties to help plants survive tough conditions. By carefully crossing plants with useful traits like deep roots or pest resistance, scientists create new hybrids and varieties that grow better, give more yield, and handle stress like drought or floods. This isn't about making "super plants," but about helping crops reach their full potential.

For example, plants from deserts may have drought-tolerant genes, while those from flood areas can survive underwater. Using these traits, breeders can quickly develop climate-resilient crops, helping farmers deal with changing weather and protect food supplies.

How Hybrid Rice Nutrient Uptake Helps Climate-Resilient Farming

Hybrid rice takes in nutrients in a more efficient way, which helps in growing more food while protecting the environment. Here's how:

Uses Fertilizers Better: Hybrid rice can absorb and use nitrogen more efficiently than regular rice. This means farmers need to use less fertilizer, which reduces pollution and harmful gases like nitrous oxide that cause climate change.

Grows Faster: Many hybrid rice types grow and mature quickly. So, the fields don't need to stay flooded for long, which lowers methane emissions, that contributes to global warming.

Stronger Against Climate Stress: Because of better nutrient use, hybrid rice grows strong roots and healthy plants. This helps it survive in tough conditions like drought, floods, or poor soil and other problems that are more common due to climate change.

Works Well with Smart Farming Methods: Hybrid rice gives even better results when used with climate-smart practices like:

Alternate Wetting and Drying (AWD): Saving water by not keeping fields always flooded.

Better Fertilizer Use: Giving the right amount at the right time.

System of Rice Intensification (SRI): Planting fewer but stronger plants to get better yields with less

water and fertilizer.

Room for New Technologies: Tools like gene editing, smart computer models for breeding, and root studies can make hybrid rice even better in the future.

In short, hybrid rice helps farmers grow more with fewer inputs (like water and fertilizer), while also cutting down on pollution and making farms stronger against climate change.

Key Traits for a Tougher Future

To create crops that can handle climate change, plant breeders work on improving certain natural features that help plants survive tough weather. These features are carefully chosen and added to new crop types, turning them into strong "survivors" that can face harsh climate conditions.

Drought Tolerance: Growing Strong with Less Water: With water becoming harder to find and droughts happening more often, scientists are working on crops that don't need much water to survive. These smart plants have deep roots that reach hidden water underground, leaf pores that help save water, and make the most out of every drop. Thanks to these features, farmers can still get good harvests during long dry spells, and they don't need as much irrigation, saving precious water resources (Ilyas *et al.*, 2021).

Heat Resistance: Beating the Heat: Hotter days are tough on crops. When it gets too hot, plants struggle to grow, make food, or produce seeds. That's why breeders are creating crops that stay cool and keep functioning even in high heat. These plants produce special "heat shock proteins" that protect them, and have leaf shapes that let air move through better, helping them cool down. These heat-smart crops are vital for farming in hotter regions (Wahid *et al.*, 2007).

Flood Survival: Staying Strong under Water: In areas with heavy rains and floods, crops need to survive being underwater. Some rice plants now have a special gene called *Sub1*, which helps them go into a sleep-like state during floods. This gives them time to wait it out until the water goes down, and then they grow again. These flood-surviving rice varieties have changed farming in flood-prone regions, saving harvests that used to be lost (Ilyas *et al.*, 2021).

Salinity Endurance: Thriving in Salty Soils: When salt builds up in the soil, often due to sea-level rise or poor irrigation, many crops struggle to grow. Scientists are now developing plants that can survive in salty conditions. These crops either block the salt, store it safely in parts of the plant, or push it out entirely. They help turn damaged, salty land back into productive farmland (Sonu *et al.*, 2024)

Pest and Disease Resistance: Built-in Protection: As the climate shifts, pests and plant diseases are spreading to new places. Some are becoming stronger and harder to control. Breeding crops with natural resistance to many pests and diseases helps reduce the need for chemical pesticides. These built-in defenses protect harvests and support healthier, more sustainable farming.

Yield Stability and Nutrition: Reliable and Healthy Harvests: Resilient crops need to do more

than survive; they must produce stable harvests and stay nutritious. Some plants are bred to keep flowering and growing even under stress. Others are made to hold onto nutrients like iron and zinc, which can drop in hot or dry weather.

Modern Breeding Tools: Modern plant breeding integrates traditional methods with sophisticated technologies, accelerating the development of new varieties and allowing for precision in crop improvement:

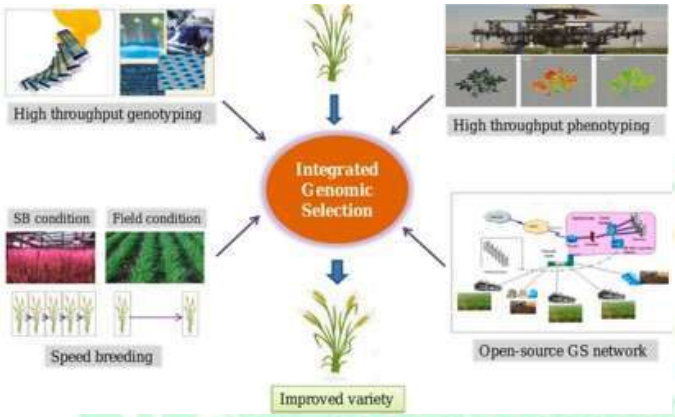

Figure 1: Integrated Genomic Selection (Krishnappa *et al*., 2021)

Genomic Selection (GS) and Marker-Assisted Breeding

Traditional breeding takes many years to develop a new crop variety. Genomic Selection (GS) makes this process much faster by using special DNA markers to predict how good a plant will be even before it is planted in the field. This helps scientists choose the best plants more accurately, especially for complex traits like drought or heat tolerance. As a result, the breeding process becomes quicker and more efficient. By studying all of a plant's genes, scientists can decide which plants to cross, saving a lot of time and effort in developing improved varieties.

Speed Breeding: Speed breeding is a method that improves plant growth by carefully controlling conditions like light, temperature, and day length. This allows plants to grow faster, so several generations (up to four to six) can be produced in a single year in special growing environments. When used along with genomic tools, speed breeding helps create new climate-resilient crops much faster. This quick cycle gives breeders more chances to test and improve plant traits in less time, which is very important as the climate changes rapidly.

Gene Editing (CRISPR/Cas9): Gene editing tools like CRISPR/Cas9 allow scientists to make very accurate changes to a plant's DNA. This means they can improve useful traits, like better resistance to heat, pests, or other problems without adding genes from other species. With this tool, scientists can turn genes on or off or make small edits in the DNA to improve how a plant grows. It offers very high precision, helping to develop stronger, climate-ready crops faster and more effectively (Zhang *et al*., 2021).

Challenges and Collaboration

While progress is significant, challenges remain. It's hard to make plant varieties perfect for very specific local places. For example, a drought-resistant plant might not work the same way everywhere, so we need to keep researching and testing it in different areas. Also, it costs a lot to create and use these new technologies. Rules and money problems can stop them from being used

Real-World Resilience: Success Stories

Table 1: Climate-Resilient crop varieties and its key features

Climate-Resilient Crop Variety	Key Feature	Impact & Benefits	Regions Benefited	Reference
Drought-tolerant Maize (DroughtGuard™)	Withstands drought, 10-20% yield advantage	Supports food production in water-stressed conditions, stabilizes farmer incomes, and prevents food shortages	Sub-Saharan Africa, Asia	Ilyas *et al*., 2021
Heat-tolerant Wheat ('Sunshine' variety)	Maintains yield under high temperatures	Ensures stable production in wheat-growing regions despite increasing heatwaves	Australia, Major wheat-producing regions	Wahid *et al*., 2007
Flood-tolerant Rice (Swarna-Sub1)	Survives up to 2 weeks of flooding	Enables recovery of harvests post-submergence, reduces economic losses and food insecurity	Flood-prone areas of South Asia	Oladosu *et al*., 2020
Salinity-tolerant Rice (FL478)	Thrives in high-salinity soils	Maintains productivity in salt-affected soils, revitalizes coastal and saline-affected agricultural lands	Coastal and saline-affected regions	Sonu *et al*., 2024
Climate-smart Barley (New varieties)	Improved nutrient-use efficiency, reduced methane emissions	Sustainable production with less fertilizer, lower environmental footprint, good yields	Diverse barley-growing regions	Abbass *et al*., 2022

widely, especially in poorer countries that need them most. Some people also don't like gene-edited crops, even though they can be very helpful. The path forward demands sustained investment in research, fostering international collaboration, and critically, involving farmers themselves in the breeding process. Participatory breeding programs, where farmers provide invaluable insights into local environmental conditions and desired traits, ensure that new varieties truly meet their practical needs and are readily adopted. By integrating traditional knowledge with modern science, and focusing on multi-dimensional traits, we can continue to develop an agriculture that is not just productive, but truly resilient, safeguarding our food future. Overcoming these challenges will require concerted efforts from governments, scientists, NGOs, and local communities working in synergy.

Conclusion: Sowing Seeds of Hope

The use of hybrid plants and new crop varieties in farming is not just about science; it is a very important way to keep food safe for everyone around the world. Through careful research, new ideas in plant breeding, and mixing old farming knowledge with modern technology, we are giving crops the natural tools they need to survive in a changing climate. The success stories from farms worldwide show us that there is hope. If we keep investing in and supporting these climate-strong crops, we can create a farming system that adjusts to changes in weather and climate. This will help make sure that future generations have enough healthy food to eat, no matter what the climate is like. It can turn a big problem into a chance to build a stronger and more sustainable food system for the world.

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India: The Only Country Producing All Commercial Silks

Harish Reddy C.

Abstract

India holds a unique and unmatched position in the global sericulture landscape by being the only country that produces all five major types of commercially valuable silk: mulberry, eri, tasar, muga and tropical tasar. Each of these silks has distinct biological sources, rearing environments, spinning techniques and end uses. This diversity stems from India's rich agro-climatic zones, deep cultural heritage, indigenous knowledge systems and government-supported sericulture programs. While China dominates the global silk trade with mulberry silk, India's strength lies in its biodiversity and eco-socioeconomic engagement with sericulture across varied tribal and rural populations. This article explores the biology, cultivation methods, regional distribution, cultural significance, and economic potential of each silk variety, showcasing India's unique position as the true rainbow of sericulture.

Introduction

Silk, long considered the "queen of textiles", has woven its way through history as a fabric of luxury, beauty, and cultural expression. Though silk originated in ancient China, it was in India that the art of rearing multiple silkworm species and producing diverse silk types flourished into a multi-dimensional industry. Today, India stands out globally as the only country producing all five commercially viable types of silk, namely mulberry, eri, tasar, muga and tropical tasar. While mulberry silk constitutes the majority of global silk production, it is the wild silks-eri, tasar, muga and their tropical variants, that gives India its distinctive edge. These silks are deeply intertwined with tribal traditions, eco-friendly practices and rural employment. This article delves into each of these silk types, examining their biological origin, production techniques, geographic range, socio-economic importance and contribution to India's silk mosaic.

Mulberry Silk: The Backbone of Indian Sericulture

Biological and Rearing Characteristics: Mulberry silk is produced by the domesticated silkworm *Bombyx mori*, which exclusively feeds on mulberry (*Morus alba*) leaves. These silkworms are completely dependent on humans for survival, having lost the ability to fly or find food on their own due to centuries of domestication.

Distribution in India: Mulberry sericulture is predominantly practiced in the southern states of Karnataka, Andhra Pradesh, Tamil Nadu, as well as in West Bengal and Jammu & Kashmir. Karnataka

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alone contributes over 35% of India's mulberry silk.

Economic Importance

- ✓ Mulberry silk contributes about 70% of India's total raw silk production.
- ✓ It supports over 7 lakh sericulture farming families.
- ✓ India is the second-largest producer of mulberry silk globally after China.

Cultural and Commercial Uses: The fabric is known for its lustrous, smooth and fine texture, making it ideal for sarees, garments and export-quality textiles. Kanjeevaram, Mysore and Banarasi silks are made from high-quality mulberry silk.

Eri Silk: The Peace Silk of the Northeast

Biological and Rearing Characteristics: Eri silk comes from the *Samia ricini* or *Philosamia ricini* moth. Unlike other silk-producing species, the pupa is not killed during cocoon harvesting, making it eco- and cruelty-free, often marketed as "Ahimsa silk". Eri silkworms feed on castor (*Ricinus communis*) and kesseru (*Heteropanax fragrans*) leaves, and the silk is spun rather than reeled due to its open-ended cocoon.

Distribution in India: Predominantly in Assam, Meghalaya, Arunachal Pradesh, Nagaland and parts of Odisha and Bihar. Assam is the largest producer of eri silk.

Socio-Economic and Cultural Importance

- ✓ Closely linked with tribal livelihoods, especially among women.
- ✓ Plays a significant role in sustainable rural development.
- ✓ Used in warm shawls, stoles and home furnishings, especially in Buddhist monastic robes.

Properties

- ✓ Eri silk is soft, warm and durable, making it suitable for winter clothing.
- ✓ It's highly breathable, biodegradable, and dyed using natural colours.

Tasar Silk: The Forest Silk of Central India

Biological and Rearing Characteristics: Tasar silk is obtained from *Antheraea mylitta* and *Antheraea proylei*, moths that feed on terminalia (Arjun and Asan) trees. Unlike *Bombyx mori*, these are semi-domesticated or wild silkworms reared in forested areas.

Distribution in India: Found in Jharkhand, Chhattisgarh, Odisha, Madhya Pradesh and West Bengal. Jharkhand is the Tasar capital of India.

Tribal Integration and Livelihood

- ✓ Tasar sericulture is deeply embedded in tribal economies, especially among Santhals, Gonds and Oraon communities.
- ✓ Over 2 lakh tribal families are involved in tasar silk activities.

Properties and Products

- ✓ Tasar silk is known for its coppery sheen, texture and strength.
- ✓ Used in both textiles and furnishings.
- ✓ The fabric is rougher than mulberry silk but prized for its earthy look.

Muga Silk: The Golden Silk of Assam

Biological and Rearing Characteristics: Muga silk

is produced by *Antheraea assamensis*, a wild silkworm endemic to Assam. It feeds on *som* (*Machilus bombycina*) and *soalu* (*Litsea polyantha*) leaves.

Exclusive to Assam

- ✓ Muga is geographically exclusive to Assam.
- ✓ The silkworm thrives only in the Brahmaputra Valley's unique climate and flora.

Cultural and Heritage Significance

- ✓ Muga silk has GI (Geographical Indication) status.
- ✓ Traditionally used in Mekhela Chador, wedding attire and ritual garments.
- ✓ Known for its natural golden-yellow luster, which improves with washing.

Properties

- ✓ One of the strongest natural fibres.
- ✓ Resists UV radiation, making it ideal for long-lasting garments.

Tropical Tasar: India's Wild Adaptation

Tropical vs. Temperate Tasar: Tropical tasar comes from *Antheraea mylitta*, while temperate tasar (China/Japan) comes from *Antheraea pernyi*. India's forests allow both commercial and wild tasar rearing, especially in central tribal belts.

Region and Adaptation

- ✓ Found in Odisha, Jharkhand, Chhattisgarh and Maharashtra.
- ✓ Tropical tasar worms are reared both in natural forests and plantation systems.

Livelihood and Value Chain

- ✓ Enhances tribal incomes through Non-Timber Forest Products (NTFPs).
- ✓ Women are engaged in cocoon collection, reeling and weaving.

Government Schemes and R&D

- ✓ Central Silk Board (CSB) under the Ministry of Textiles coordinates sericulture development.
- ✓ Integrated Sericulture Development Projects (ISDP) and Cluster Promotion Programmes focus on wild silk value chains.
- ✓ Research institutes like CSTRI, RSRS and CMER&TI promote region-specific innovations in rearing and reeling.

Challenges and Opportunities

Challenges

- ✓ Deforestation and habitat loss for wild silks
- ✓ Climate sensitivity of muga and tasar species
- ✓ Low technological penetration in tribal areas
- ✓ Market linkage gaps for non-mulberry silks

Opportunities

- ✓ Rising demand for ethical (eri) and organic silks
- ✓ Export potential for value-added wild silk products
- ✓ Eco-tourism and silk-based rural entrepreneurship
- ✓ Geographical Indication branding for regional silks

Conclusion

India's claim as the only country producing all commercial silks is not merely a statistic, it reflects a rich convergence of biodiversity, tradition, rural livelihoods and innovation. While mulberry silk continues to dominate volumes, the wild silks-tasar,

muga, eri and tropical tasar, offer cultural pride, ecological relevance and global market potential. Preserving and promoting this unique silk diversity can empower tribal communities, conserve forest ecosystems and elevate India's position in sustainable luxury textiles.

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Groundwater Depletion in India: Drivers, Impacts and the Way Forward

M. K. Meena, Ravi Dupdal, Anand Gupta and Rama Pal

Introduction

Groundwater is one of India's most vital natural resources, supporting agriculture, drinking water needs, and various industries. It serves as the backbone of irrigation and provides nearly 85% of rural drinking water and around 60% of the agricultural water supply. India is the largest consumer of groundwater in the world, extracting more annually than the United States and China combined. However, this reliance has led to serious challenges; groundwater levels are falling at alarming rates across many parts of the country. The situation poses a direct threat to water security, food production, and livelihoods. Understanding the causes and consequences of this depletion is essential for formulating effective solutions. This article explores the key reasons behind India's groundwater crisis and the far-reaching concerns it raises.

Causes of Groundwater Depletion: Table 1 and 2 explain the major causes of groundwater depletion along with solution and policy recommendation to address the issue.

Impact of Groundwater depletion on different sectors in India: Groundwater depletion is an escalating concern in India, impacting multiple sectors. Below graph outlines the cascading effects across the environment, agriculture, society and public health. Understanding these impacts is crucial for sustainable water resource management.

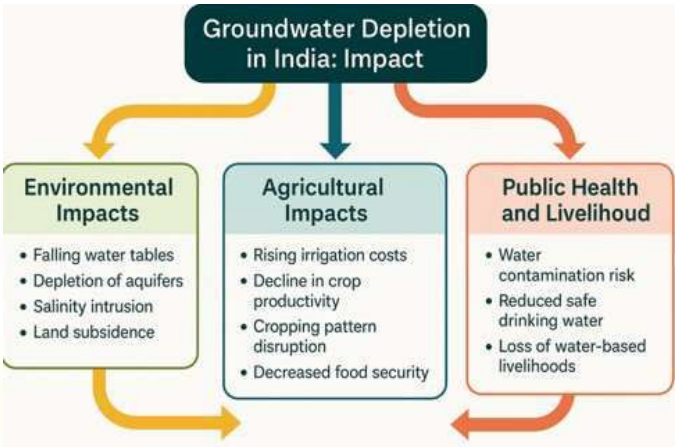

Fig. 1: Impact of Groundwater depletion in India

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Table 1: Causes of groundwater depletion in India

Cause	Description	Reference	Impacts
Over-irrigation in agriculture	Excessive groundwater used for water-intensive crops like rice and sugarcane, especially in Punjab, Haryana, and western UP.	Central Ground Water Board (CGWB), 2022	Rapid groundwater decline; salinity buildup; declining agricultural sustainability
Free/subsidized electricity for farmers	Encourages unrestricted bore well pumping, leading to over-extraction.	NITI Aayog, 2020	Deepening water tables; increased electricity consumption
Unsustainable cropping patterns	Rice in dry zones and sugarcane in drought-prone regions result in demand-supply mismatch.	ICAR, 2021	Resource mismatch; long-term aquifer stress
Urbanization & concretization	Impermeable surfaces block natural recharge; growing urban demand increases extraction.	TERI, 2021	Urban water crisis; dependence on private borewells
Decline of traditional water systems	Disuse and encroachment of tanks, step wells, and ponds reduce recharge potential.	Ministry of Jal Shakti, 2019	Reduced recharge; increased surface runoff
Climate change & erratic rainfall	Delayed or deficient monsoons reduce recharge; intense rain leads to runoff instead of infiltration.	IMD & IPCC Report, 2022	Droughts; dry wells; crop failures
Lack of regulation and monitoring	Groundwater remains largely unregulated; open-access leads to "tragedy of the commons."	World Bank, 2021	Aquifer depletion; inter-user conflict
Pollution of surface water sources	Rivers and lakes being polluted drive users toward groundwater even when not sustainable.	CPCB Annual Report, 2020	Excessive pressure on aquifers; water quality deterioration

Table 2: Solutions and policy recommendations to address groundwater depletion in India

Intervention	Description	Reference	Impacts
Micro-irrigation (Drip/Sprinkler)	Efficient water delivery minimizes wastage and saves 30–50% water.	PMKSY, 2021	Reduces over-extraction; improves water-use efficiency
Crop Diversification	Promoting millets, pulses, and oilseeds instead of paddy/sugarcane in arid regions.	Govt. of Punjab Crop Diversification Program, 2020	Reduces water demand; improves soil health
Recharge structures	Construction of check dams, percolation tanks, farm ponds, and recharge pits to increase groundwater recharge.	MGNREGA + Jal Shakti Abhiyan	Enhances aquifer replenishment; mitigates seasonal scarcity
Groundwater regulation & metering	Strict monitoring of groundwater withdrawal through water meters and permits.	Atal Bhujal Yojana (World Bank assisted), 2020	Prevents overuse; promotes accountability among users
Use of treated wastewater	Recycling municipal wastewater for industrial/agricultural use to reduce dependency on fresh groundwater.	CPCB Guidelines, Tamil Nadu reuse initiatives	Reduces freshwater demand; protects aquifers
Rainwater harvesting	Mandating rooftop harvesting in urban and rural areas.	Urban Building Codes in Chennai, Bangalore, Delhi	Improves recharge; reduces urban dependency on borewells
Awareness and community participation	Involving farmers and communities in water budgeting and local governance (Pani Panchayats, Water User Groups).	Andhra Pradesh WALTA Act, Jal Shakti Abhiyan	Promotes behavioral change; enhances local responsibility
Digital mapping and water accounting	Using GIS and remote sensing for aquifer mapping, usage tracking, and predictive modeling.	National Aquifer Mapping Program (NAQUIM), CGWB	Informed policy-making; targeted interventions

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Eyes in the Sky, Intelligence on the Ground: Revolutionizing Crop Protection with AI-Powered Pest and Disease Detection

Suvojit Bose, Sourav Mollick, Subhadwip Ghorai and Soham Hazra

Abstract

Traditional methods of pest and disease detection in agriculture often rely on manual scouting, which is time-consuming, labour-intensive, and prone to human error. Early detection is crucial for effective intervention and minimizing crop losses. Artificial intelligence (AI), coupled with advancements in imaging technology such as drones and high-resolution cameras, offers a transformative solution. This article explores the burgeoning field of AI-powered pest and disease detection in agriculture. It delves into the core technologies involved, including computer vision and deep learning algorithms, and examines how they are being utilized to identify and classify various threats to crop health. Furthermore, the article discusses the quantifiable benefits of this technology, such as early and accurate detection, reduced pesticide use, improved resource management, and enhanced crop yields. Real-world applications and the challenges and opportunities associated with the widespread adoption of AI-driven crop protection are also explored, highlighting the potential of this technology to reshape modern farming practices in regions like West Bengal, and beyond.

Introduction: The Old Ways and the New

The rhythmic hum of a drone slicing through the humid air over a paddy field in Howrah, West Bengal, is no longer an uncommon sight. While once a novelty, these aerial vehicles are increasingly becoming vital tools in the hands of farmers, empowered by the sophisticated capabilities of artificial intelligence. One of the most promising applications of this synergy lies in the early and accurate detection of pests and diseases, a perennial challenge that can decimate harvests and threaten the livelihoods of agricultural communities. For generations, farmers have relied on their keen eyes and years of experience to spot the tell-tale signs of infestation or infection. This crucial practice, however, is time-consuming, labor-intensive, and often misses problems in their early stages. The vastness of modern farms further exacerbates this challenge, making comprehensive and timely scouting a logistical nightmare. The integration of AI into agriculture represents a paradigm shift, moving farming from a reactive to a proactive and data-driven endeavor.

AI's Approach: Seeing What We Miss

AI's ability to provide an unprecedented level of insight into crop health is rooted in advanced

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computer vision and deep learning. The process begins with sophisticated data collection, moving beyond simple visual inspection. This involves capturing high-resolution images from various sources, including:

Drones (UAVs): Equipped with high-resolution RGB cameras for visual data, as well as specialized multispectral and hyperspectral sensors. These sensors capture light in different wavelength bands (e.g., near-infrared) to measure plant stress and health parameters that are invisible to the human eye, often before any physical symptoms appear.

Ground-based devices: Automated robots and handheld devices that can capture close-up images of leaves, stems, and fruits for detailed analysis.

Once the data is collected, it is fed into powerful deep learning models that have been trained on vast datasets of healthy and diseased plants. The most common and effective of these are Convolutional Neural Networks (CNNs). CNNs are specifically designed to process visual data by automatically learning to recognize features such as color, texture, and shape. For example, a CNN can be trained to distinguish the subtle discoloration and pattern of a fungal infection on a paddy leaf from a simple nutrient deficiency. Other advanced models, such as Vision Transformers (ViTs) and real-time object detection models like YOLO (You Only Look Once), are also being employed to rapidly and accurately identify affected areas and classify threats. A key challenge in training these models is acquiring a large enough and sufficiently diverse dataset. This is where Generative AI, particularly through Generative Adversarial Networks (GANs), plays a crucial role. GANs can create synthetic, realistic images of diseased crops, augmenting the training data and allowing the models to learn from a wider variety of scenarios, including different stages of disease progression and varying environmental conditions. This helps to overcome data scarcity and improves the model's performance and general-izability.

The Quantifiable Benefits of Smart Crop Protection

The adoption of AI in crop protection delivers tangible benefits that directly impact a farmer's bottom line and the environment. These are not merely theoretical advantages but quantifiable gains:

Early and Accurate Detection: AI systems can detect problems much earlier than manual scouting. By analyzing data from multispectral sensors, models can identify plant stress through changes in vegetation indices like the Normalized Difference Vegetation Index (NDVI), long before a farmer can see any visual sign of disease. This allows for timely intervention before significant damage occurs, potentially preventing a small, localized issue from becoming a field-wide epidemic. Studies have shown that AI-powered systems can achieve a mean accuracy of over 90% in detecting specific crop diseases.

Reduced Pesticide Use: By precisely identifying the type and exact location of an infestation, AI enables

targeted, spot-spraying applications instead of broad-spectrum blanket spraying. This practice, known as precision agriculture, can lead to a reduction of herbicide application by 50% or more, a significant saving in a farmer's operational costs. It also has a profound positive impact on the environment by minimizing chemical runoff, protecting beneficial insects, and preserving soil health.

Improved Resource Management and Economic Resilience: AI-powered solutions enable farmers to optimize their use of valuable resources. With precise information on crop health, they can apply fertilizers, pesticides, and water only where and when it's needed. This leads to reduced waste, lower labor costs, and increased operational efficiency. Ultimately, these cost savings, combined with improved yields and crop quality, lead to a substantial increase in profitability and a more economically resilient farming operation.

Enhanced Crop Yields: By mitigating the impact of pests and diseases more effectively and efficiently, AI-powered detection ensures healthier crops and higher yields. This allows farmers to consistently meet market demands and command better prices for their produce, contributing to food security and the overall prosperity of farming communities.

Real-World Applications and the Roadblocks

The practical applications of this technology are rapidly expanding across various crops. In regions like West Bengal, where rice is a staple crop, CNN-based models are being developed and tested to detect specific issues like brown spot disease and stem borers with high accuracy. In other agricultural sectors, AI is used to identify downy mildew in grapes, a common fungal disease, or to detect fruit flies in orchards before they cause widespread damage. Despite the proven benefits, the widespread adoption of AI in agriculture, especially for smallholder farmers, faces significant hurdles. These roadblocks include:

High Initial Investment: The cost of acquiring AI-compatible hardware, such as drones and high-resolution sensors, along with the necessary software and data subscriptions, can be prohibitively expensive for small-scale farmers who operate on thin profit margins.

Lack of Digital Literacy and Skills: Many farmers lack the technical knowledge to effectively operate and interpret data from these complex AI systems. There is a critical need for accessible, locally relevant training and support to bridge this knowledge gap.

Inadequate Infrastructure: Reliable internet connectivity and a stable power supply are essential for AI tools that rely on cloud-based processing and real-time data transfer. Unfortunately, these are often absent in the rural areas where agriculture is a primary livelihood.

Data-Related Challenges: AI models are only as good as the data they are trained on. There is a scarcity of high-quality, labeled datasets that accurately represent the diverse pest and disease profiles of various crops in different geographical and climatic conditions.

Furthermore, concerns about data privacy and ownership can create a barrier to trust and adoption.

Conclusion: A New Era of Farming

Despite these challenges, the trajectory of AI in agriculture is clear. As the technology becomes more affordable and user-friendly, and as governments and private organizations invest in rural infrastructure and farmer education, the potential for widespread adoption is immense. The future of AI in this field will likely involve the integration of multiple systems: autonomous drones not only for scouting but also for robotic precision spraying; multi-modal AI systems that combine aerial imagery with soil health, weather, and historical data to predict outbreaks; and mobile applications that put the power of AI directly into the hands of every farmer. This new era of farming, where AI serves as a vigilant partner, promises to empower farmers with "eyes in the sky and intelligence on the ground," enabling them to cultivate healthier crops, protect their livelihoods, and contribute to a more sustainable, precise, and secure food future for all.

Overview of Solid Waste Management and Waste Valorization

Anto Rashwin A. and Jayashree R.

Abstract

Solid waste management (SWM) is a pressing global issue, particularly in urban areas. This article provides a simplified, scientific overview of SWM, highlighting its critical importance today. It delves into the sources and composition of waste, traditional disposal and recycling methods, and the innovative concept of waste valorization, turning waste into valuable resources. The article also addresses the persistent challenges in current SWM practices and looks towards future innovations and a positive path for sustainable waste management.

Introduction

In our daily lives, we produce waste. From the food we eat to the products we use, waste generation is an unavoidable consequence of modern living. While small, these individual acts of discarding items contribute to a colossal problem: solid waste. In both bustling cities and quieter towns, managing this ever-increasing volume of trash has become a monumental challenge for authorities worldwide. It is not just about tidiness; it is about protecting our environment, our health, and ensuring a sustainable future for generations to come. The sheer amount of waste we produce puts a strain on municipal budgets, infrastructure and most importantly, our planet.

Sources and Components of Solid Waste

Solid waste is not a single entity; it is a diverse mix of materials that come from various sources. The primary culprit for many of us is our own households. Think of kitchen scraps, packaging materials, old clothes, and paper this is known as municipal solid waste (MSW). Beyond our homes, waste also stems from businesses, industries, and agricultural activities.

The composition of this waste varies greatly depending on where you are and how people live. However, common categories include:

Organic Waste: This includes food scraps, yard trimmings, and other biodegradable materials. It is a significant portion of household waste and is particularly important for management strategies.

Plastics: From bottles and bags to packaging, plastics are everywhere. Their durability makes them a persistent problem when not managed correctly.

Paper and Cardboard: Commonly found in packaging and documents, these are often recyclable.

Metals: Cans, foils, and various metallic components contribute to the waste stream.

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Glass: Bottles and containers made of glass are also a significant component, and largely recyclable.

E-waste: With the rapid advancement of technology, electronic waste old computers, phones, and batteries is a growing concern due to its hazardous components.

Textiles and Leather: Old clothing, shoes, and other fabric items also find their way into waste.

Wood: From furniture to construction scraps, wood waste is another component.

Inert Materials: This category includes items like rocks, soil, and construction debris.

Fig. 1: Different Stages in the SWM service Framework (Shahab and Anjum, 2021)

Disposal and Recycling

For decades, the most common way to deal with solid waste has been through disposal. This primarily involves:

Landfills: These are designated areas where waste is buried. While they are a traditional method, modern landfills are engineered with liners and systems to contain waste and manage leachate (liquid that seeps from waste) and gases. However, landfill space is finite, and they can pose environmental risks if not managed properly.

Incineration: This involves burning waste, often with the aim of reducing its volume and sometimes generating energy. While it can be effective, incineration needs careful control to prevent air pollution and the release of harmful substances.

Alongside disposal, recycling has become a cornerstone of modern waste management. Recycling is the process of collecting and reprocessing waste materials to create new products. Common recyclables include paper, glass, metals, and certain types of plastics. Effective recycling programs rely on:

Source Separation: Encouraging people to sort their waste at home.

Collection Systems: Efficient systems to collect separated recyclables.

Processing Facilities: Centers where materials are sorted, cleaned, and prepared for remanufacturing.

Fig. 2: Waste hierarchy (Mandree *et al.*, 2023)

The Concept of Waste Valorization

Beyond just disposal and recycling, there is a more innovative concept called "valorization." This means transforming waste materials into something valuable, creating new products or energy from what was once considered trash.

Fig. 3: Potential beneficiation of Agro-industrial waste (Khan *et al.*, 2015)

It is about seeing waste not as a problem, but as a resource.

Examples of waste valorization include:

Composting: The biological decomposition of organic waste into a nutrient-rich soil conditioner, which can be used to improve soil health in agriculture.

Anaerobic Digestion: This process breaks down organic waste in the absence of oxygen, producing biogas (a source of renewable energy) and digestate (a nutrient-rich residue that can also be used as fertilizer).

Waste-to-Energy (WtE): Technologies that convert waste into heat, electricity, or fuel.

Producing Biofuels and Biochemicals: Using organic waste as a feedstock to create valuable products like ethanol or plastics.

Extracting Valuable Materials: Recovering specific components from complex waste streams, like metals from electronic waste.

Challenges in Solid Waste Management

Despite advancements, solid waste management faces significant problems such as,

Increasing Waste Generation: Population growth, urbanization, and changing consumption patterns mean more waste is being produced than ever before.

Inadequate Infrastructure: Many regions, especially in developing countries, lack the necessary facilities for proper collection, sorting, treatment, and disposal.

Financial Constraints: Implementing effective SWM systems requires substantial investment, which can be a barrier.

Public Awareness and Participation: The success of SWM heavily relies on public engagement in practices like waste segregation and responsible disposal.

Complex Waste Composition: The heterogeneity of waste makes sorting and treatment challenging.

Policy and Enforcement Gaps: Inconsistent regulations and weak enforcement can undermine SWM efforts.

Hazardous Waste Management: Improper disposal of household hazardous waste (like batteries and old paints) poses significant environmental and health risks.

Innovations in the field of Sustainable Solid Waste Management

The future of waste management is based on innovation and integrated approaches. Key areas of focus include:

Advanced Sorting Technologies: Utilizing AI and automated systems for more efficient waste segregation.

Circular Economy Principles: Designing products for longevity, repairability, and recyclability.

Smart Waste Management: Employing technology like sensors and data analytics to optimize collection routes and monitor waste streams.

Promoting Reuse and Reduction: Shifting focus from end-of-pipe solutions to preventing waste generation in the first place.

Extended Producer Responsibility (EPR): Holding manufacturers accountable for the end-of-life

management of their products.

Investing in Valorization Technologies: Further developing and scaling up methods to convert waste into valuable resources and energy.

Enhanced Public Education: Continuous efforts to raise awareness and foster sustainable waste management habits.

Policy Innovation: Implementing robust policies, incentives, and regulations to support sustainable SWM.

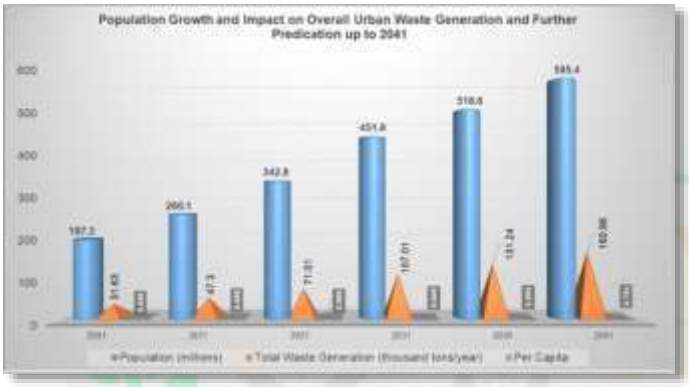

Fig. 4: Prediction of waste generation for the urban population in India (Pal and Bhatia, 2022)

Conclusion

By adopting these innovative strategies and promoting collaboration, we can move towards a future where the generation of solid waste is minimized, resources are conserved, and our environment is protected. Solid waste management is not just a technical or logistical challenge; it is a societal imperative for a healthier planet and a more sustainable tomorrow.

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Cauliflower: An Important Vegetable Crop

Simran Choudhary and Vibhootee Garg

Introduction

Cauliflower (*Brassica oleracea* var. botrytis L.) is one of the most important Cole crops belonging to the family Cruciferae (Brassicaceae). It is native to the Mediterranean region but has gained worldwide importance due to its high nutritional value and consumer preference. India is one of the leading producers of cauliflower, contributing significantly to both domestic consumption and export. It is a cool-season crop grown extensively in northern India during *rabi* season but early and mid-season varieties allow production almost throughout the year in different regions.

Importance of Cauliflower

Nutritional Value

- ✓ Rich in vitamin C, vitamin K, folate, dietary fiber, and antioxidants.
- ✓ Contains bioactive compounds such as glucosinolates that have anti-cancer properties.

Economic Importance

- ✓ High demand in urban and rural markets.
- ✓ Provides quick returns to farmers due to shorter growing period.
- ✓ Export potential to Middle East and European countries.

Dietary Significance

- ✓ Consumed as fresh vegetable, pickles, soups, curries, and processed products.
- ✓ Low calorie content makes it suitable for health-conscious consumers.

Botanical and Agronomic Classification

Botanical Name: *Brassica oleracea* var. botrytis L.

Family: Brassicaceae (Cruciferae)

Chromosome Number = 2n = 18

Edible Part: Curd (immature inflorescence meristem)

Climatic Requirement: Cool, moist climate with optimum temperature of 15-20°C. High temperature leads to lose or leafy curd formation.

Improved Varieties and Hybrids

ICAR Institutes and SAUs have released many varieties:

Early Varieties: Pusa Early Synthetic, Pusa Deepali, Pant Gobhi-2

Mid-Season Varieties: Pusa Shubhra, Pusa Snowball-1, Pusa Synthetic

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Late Varieties: Pusa Snowball-16, Dania, Pant Shubhra

Hybrids: Pusa Hybrid-2, Pusa Hybrid-3, NS 60, Himani

Selection of varieties depends on temperature requirement and season of planting.

Cultivation Practices

Soil and Climate

- ✓ Well-drained loamy soils with pH 6.0-7.0 are ideal.
- ✓ Sensitive to high temperatures and waterlogging.

Nursery Raising

- ✓ Seeds are sown in raised nursery beds under shade nets or poly tunnels.
- ✓ Seed rate: 400-500 g ha^{-1}.
- ✓ Seedlings are ready in 25-30 days.

Field Preparation and Transplanting

- ✓ 3-4 ploughings followed by FYM application (20-25 t ha^{-1}).
- ✓ Seedlings transplanted at 45 × 45 cm spacing (varies with season).

Nutrient Management

- ✓ Fertilizer dose: 120-150 kg N, 60-80 kg P_2O_5, 60-80 kg K_2O ha^{-1}.
- ✓ Apply half N + full P + K at transplanting and remaining N in two splits.
- ✓ Foliar spray of boron and molybdenum prevents physiological disorders.

Irrigation

- ✓ Requires frequent irrigation (10-15 days interval).
- ✓ Critical stages: curd initiation and development.

Weed Management: Two hand weeding or pre-emergence herbicide like pendimethalin (1.0 kg a.i. ha^{-1}).

Plant Protection

Diseases: Downy mildew, black rot, damping off.

Control: Seed treatment with fungicides (Captan/ Thiram), resistant varieties, crop rotation.

Insect Pests: Diamondback moth, aphids, painted bug.

Control: Neem oil sprays, pheromone traps, biological control (Trichogramma).

Physiological Disorders

Buttoning: Small curd due to early sowing or nitrogen deficiency.

Raciness: Loose granular curd due to high temperature.

Browning: Boron deficiency.

Whiptail: Molybdenum deficiency.

Prevented by balanced nutrition and proper sowing time.

Harvesting and Yield

- ✓ Harvesting is done when curds are compact, white, and firm.
- ✓ Delayed harvesting causes yellowing and raciness.
- ✓ Average yield: 200-250 q ha^{-1} under good management.

Post-Harvest Management

- ✓ Grading based on curd size and compactness.
- ✓ Packing in bamboo baskets, crates, or perforated polybags.
- ✓ Shelf life: 45 days at room temperature, but

extended up to 3-4 weeks under cold storage (0-5°C, 90% RH).

- ✓ Value-added products: Frozen cauliflower, dehydrated florets, pickles.

Challenges in Cauliflower Production

- ✓ Susceptibility to pests and diseases.
- ✓ High post-harvest losses due to poor cold chain facilities.
- ✓ Climate sensitivity (temperature and rainfall fluctuations).
- ✓ Lack of awareness among farmers about hybrids and improved practices.
- ✓ Market price fluctuation during glut season.

Future Prospects

- ✓ Protected cultivation for off-season production.
- ✓ Development of climate-resilient and bio-fortified varieties.
- ✓ Integrated pest and nutrient management for sustainable yield.
- ✓ Processing and export promotion to reduce post-harvest losses.
- ✓ Use of digital tools like drones and sensors for precision farming.

Conclusion

Cauliflower is one of the most important vegetables in India due to its high nutritive value, economic returns, and consumer preference. Adoption of improved varieties, balanced nutrition, integrated pest management, and post-harvest handling can enhance productivity and farmer income. With increasing demand for healthy and nutritious vegetables, cauliflower cultivation holds immense potential for sustainable agriculture and export-oriented production.

Historical and Spiritual Perspectives of Vegetables in India

Simran Choudhary and Isha Verma

Introduction

Vegetables are not only a source of food and nutrition but also hold historical, cultural, and spiritual significance in India. Since ancient times, vegetables have been associated with health, Ayurveda, rituals, and religious symbolism. Ancient Indian civilization, which flourished along the Indus Valley and later under Vedic traditions, considered vegetables as sacred gifts of nature. Indian scriptures like the Vedas, Upanishads, Ayurveda, and Puranas provide references to vegetables, describing their medicinal properties and spiritual relevance. Even today, vegetables play a central role in Indian festivals, rituals, and cultural practices.

Historical Significance of Vegetables in India

Indus Valley Civilization: Archaeological findings from Harappa and Mohenjo-Daro suggest the cultivation of cucurbits, peas, onions, garlic, and leafy greens. These crops were part of the daily diet and trade.

Cultural and Festival Connections

Onam (Kerala): The grand vegetarian feast Onam Sadhya includes more than 20 vegetable dishes.

Pongal (Tamil Nadu): Freshly harvested vegetables are used in traditional dishes as offerings to the Sun God.

Makar Sankranti: Use of root and leafy vegetables in community meals.

Chhath Puja (Bihar, UP): Seasonal vegetables are offered to the Sun God.

Diwali and Navratri: Families prefer Satvik vegetable diets during fasting and worship.

Vedic and Epic Period

The Rigveda and Atharvaveda mention vegetables such as beans, gourds, and leafy greens. In the Mahabharata and Ramayana, several references to fruits and vegetables can be found, highlighting their importance in royal feasts and hermit diets.

Medieval Period

With the influence of Mughal rulers, exotic vegetables such as cauliflower, cabbage, and spinach were introduced and popularized. Mughal kitchens documented recipes of rich vegetable curries and pickles.

Spiritual Perspectives of Vegetables

- ✓ Association with Hindu Rituals
- ✓ Certain vegetables are considered sacred offer-

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ings to deities. For example:

- ✓ Pumpkin and cucumber are offered during religious rituals.
- ✓ Tulsi (though a sacred herb) is essential in worship and offerings.
- ✓ During festivals like Navratri and Ekadashi, special vegetable-based fasting diets are followed.

Symbolism in Ayurveda

- ✓ Ayurveda classifies vegetables as Satvik, Rajsik, and Tamsik foods.
- ✓ Satvik vegetables (bottle gourd, pumpkin, spinach) promote purity, calmness, and spiritual growth.
- ✓ Rajsik vegetables (brinjal, onion) stimulate energy and passion.
- ✓ Tamsik vegetables (garlic, mushrooms) are believed to dull the mind and are avoided in religious practices.
- ✓ Root vegetables like onion, garlic, potato, and carrot are avoided due to harm to soil organisms and belief in karmic consequences.

Medicinal and Spiritual Integration in Ayurveda

Onion and Garlic: Used as medicines in Ayurveda for their antimicrobial and healing properties, but avoided in spiritual fasting.

Bitter Gourd: Considered purifying and useful for balancing blood sugar.

Spinach and Green Leafy Vegetables: Rich in iron and linked to vitality and energy.

Pumpkin: Associated with detoxification and often used in rituals to ward off evil spirits.

Continuity into Modern India

Even today, vegetables carry dual importance:

- ✓ As nutritious foods essential for balanced diets.
- ✓ As spiritual elements that define fasting rules, ritual offerings, and cultural dishes.
- ✓ Government policies promoting organic vegetable farming and revival of traditional crops also highlight India's respect for heritage.

Conclusion

Vegetables in India are more than agricultural produce they are symbols of culture, spirituality, and tradition. From the Vedic chants to modern dietary guidelines, vegetables have shaped both the physical health and spiritual practices of Indian society. The historical and spiritual perspectives remind us that vegetables are not only for sustenance but also for fostering harmony with nature, health, and divinity. Thus, vegetables form an integral link between food, faith, and culture in India's rich heritage.

Protected Cultivation of Vegetable Crops for Sustainable Food Production

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Introduction

Vegetable crops play a vital role in ensuring food and nutritional security. However, open-field cultivation of vegetables faces several challenges such as climate variability, pest and disease incidence, low productivity, and post-harvest losses. Protected cultivation provides a scientific solution to overcome these limitations. Protected cultivation refers to the growing of vegetables in controlled or partially controlled environments such as greenhouses, polyhouses, shade nets, tunnels, and hydroponic structures. It allows modification of the microclimate around the plant to achieve higher productivity, better quality, and year-round supply of vegetables. In India, the adoption of protected cultivation is increasing due to government support under Mission for Integrated Development of Horticulture (MIDH), National Horticulture Mission, and State Horticulture Missions.

Importance of Protected Cultivation

Sustainable Food Production: Enables year-round vegetable supply, reducing dependence on seasonal fluctuations.

Higher Yield: Productivity is 3-5 times higher compared to open field.

Quality Production: Uniform shape, size, and better nutritive value of vegetables.

Efficient Resource Use: Water saving (40-60%) through drip irrigation and fertigation.

Climate Resilience: Crops are protected from extreme weather conditions (frost, high temperature, heavy rain).

Employment and Income: Creates opportunities for rural youth, smallholders, and women farmers.

Export Potential: Enables production of high-value crops (capsicum, cucumber, cherry tomato) meeting international quality standards.

Types of Protected Structures in Vegetable Cultivation

- ✓ Greenhouses / Polyhouses
- ✓ Made of transparent plastic sheets or glass.
- ✓ Used for high-value crops like capsicum, cucumber, tomato, lettuce.
- ✓ Temperature, humidity, and light can be controlled.

Shade Net Houses

- ✓ Covered with shade nets (35-75% shading).
- ✓ Useful for raising nurseries, leafy vegetables, and hardening seedlings.

Plastic Low Tunnels

- ✓ Small semi-circular structures with polyethylene cover.
- ✓ Used for early season cucurbits, melons, and tomatoes.

Walk-in Tunnels / Naturally Ventilated Poly-houses

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- ✓ Low-cost structures for small-scale farmers.
- ✓ Used for vegetable seedlings and short-duration crops.

Hydroponics & Vertical Farming

- ✓ Soilless cultivation using nutrient solution (hydroponics) or aeroponics.
- ✓ Ideal for urban and peri-urban farming with space constraints.

Suitable Vegetable Crops for Protected Cultivation

Fruit Vegetables: Tomato, capsicum, cucumber, brinjal, chilli, gourds.

Leafy Vegetables: Spinach, lettuce, coriander, fenugreek.

Exotic Vegetables: Broccoli, lettuce, celery, zucchini.

Seedling Production: Vegetable nurseries for large-scale farming.

Improved Practices in Protected Cultivation

Hybrid Seeds: Use of high-yielding, disease-resistant hybrids.

Soil/Media Preparation: Use of cocopeat, vermiculite, perlite in soilless media.

Irrigation & Fertigation: Automated drip systems for nutrient and water application.

IPM Practices: Sticky traps, biocontrol agents (Trichoderma, neem oil) for pest management.

Climate Control: Fans, cooling pads, and misting systems in high-tech greenhouses.

Training & Pruning: Proper crop management for indeterminate vegetables like tomato and cucumber.

Advantages of Protected Cultivation

- ✓ 3-5 times higher productivity.
- ✓ Quality produce with longer shelf life.
- ✓ Reduction in chemical pesticide usage → safer food.
- ✓ Off-season production ensures premium market price.
- ✓ Reduced post-harvest losses due to timely harvest and better handling.

Challenges in Protected Cultivation

High Initial Cost: Construction of polyhouse/ greenhouse requires large investment.

Skilled Management: Requires technical knowledge for fertigation, climate control, and pest management.

Pest and Disease Outbreaks: Closed environment may favor rapid spread.

Market Fluctuations: Price variations may affect profitability.

Energy Requirement: Climate-controlled green-houses require energy for cooling/heating.

Future Prospects

Low-Cost Structures: Development of affordable polyhouses for small farmers.

Integration with ICT: Use of sensors, drones, AI, and IoT for precision management.

Urban Agriculture: Rooftop polyhouses, vertical farming in cities.

Organic Protected Cultivation: High market demand for chemical-free vegetables.

Export-Oriented Production: Focus on exotic vegetables for international markets.

Conclusion

Protected cultivation is a modern approach to achieve sustainable food production, especially in the face of climate change and land scarcity. It ensures higher yields, better quality, resource efficiency, and continuous supply of vegetables throughout the year. To promote its adoption, emphasis should be given on capacity building of farmers, financial support, research on low-cost structures, and market linkages. Protected cultivation is not just a technology but a pathway towards resilient, profitable, and sustainable vegetable production, ensuring both farmer prosperity and consumer health.

Trichoderma in Pest and Disease Management: A Sustainable Biological Solution

Umara Rahmani, Ashok Kumar and Mohd. Nayeem

Abstract

Trichoderma, a genus of filamentous fungi found in soil and root ecosystems, plays a significant role in sustainable agriculture due to its biocontrol properties against plant pathogens and pests. As the overuse of chemical pesticides raises environmental and health concerns, the use of Trichoderma-based bioformulations is emerging as an eco-friendly and efficient alternative in pest and disease management. This article explores the mechanisms, applications, advantages, challenges, and future prospects of using *Trichoderma* species in integrated pest and disease management (IPDM) systems.

Introduction

Modern agriculture faces the dual challenge of increasing productivity while minimizing environmental impact. One of the most significant threats to crop yields is the damage caused by plant pathogens and insect pests. Traditionally, chemical pesticides have been used to control these threats; however, their continuous use has led to resistance development, residue problems, environmental pollution, and risks to human health. In response, biological control methods are gaining attention. Among them, *Trichoderma* species have emerged as one of the most effective biocontrol agents. These fungi are naturally found in the rhizosphere and are known for their antagonistic properties against a wide range of plant pathogens and certain insect pests. Their ability to promote plant growth and induce systemic resistance makes them an important component in organic and sustainable farming systems.

Taxonomy (Krick *et al.*, 2008):

Kingdom: Fungi

Phylum: Ascomycota

Class: Sordariomycetes

Genus: Trichoderma

Species: *Trichoderma harzianum*, *T. viride*, *T. asperellum*, *T. koningii*, and *T. atroviride*.

Mechanisms of Pest and Disease Management

Trichoderma species combat plant pathogens and pests through several mechanisms:

Mycoparasitism: *Trichoderma* directly attacks and parasitizes other fungi. It coils around the pathogen hyphae, penetrates them using hydrolytic enzymes (chitin-ases, glucanases, proteases), and destroys them.

Antibiosis: *Trichoderma* produces secondary metabolites, such as peptaibols, gliotoxin, viridin, and harzianic acid, which inhibit the growth and

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reproduction of pathogenic fungi and bacteria.

Competition: These fungi compete with pathogens for space and nutrients in the rhizosphere, effectively excluding them from the root zone.

Induced Systemic Resistance (ISR): *Trichoderma* can trigger the plant's immune response, making it more resistant to subsequent infections. It activates defense genes and biochemical pathways (e.g., salicylic acid and jasmonic acid pathways).

Plant Growth Promotion: Some species promote root development and nutrient uptake by producing growth regulators like indole-3-acetic acid (IAA) and solubilizing phosphates and micronutrients.

Insect Pest Suppression: Though not directly insecticidal, *Trichoderma* can reduce pest attacks by improving plant health and indirectly deterring pest colonization through ISR and secondary metabolites.

Applications in Agriculture

Seed Treatment: Seeds treated with *Trichoderma* spores germinate better and develop healthier root systems. It protects seedlings from soil-borne pathogens like *Pythium*, *Fusarium*, and *Rhizoctonia*.

Soil Application: Soil inoculation with *Trichoderma* improves soil health and creates a suppressive environment for pathogens like *Sclerotium rolfsii*, *Macrophomina phaseolina*, and nematodes.

Compost and Organic Manure Enrichment: Adding *Trichoderma* to compost enhances the decomposition process and adds beneficial microbes to the soil.

Nursery Bed Treatment: In horticulture and forestry, treating nursery soil with *Trichoderma* prevents early-stage diseases and ensures healthy transplanting.

Benefits of Using *Trichoderma*

Environmentally Friendly: Non-toxic to humans, animals, and beneficial insects.

Residue-Free: No harmful residues in soil or produce.

Cost-Effective: once applied and it will maintain its population naturally.

Sustainable: Improves soil fertility and structure.

Compatible: Can be integrated with other IPM practices and organic inputs.

Reduces dependency on chemical fungicides.

Limitations and Challenges

Sensitivity to Environmental Conditions: *Trichoderma* is affected by high temperatures, UV radiation, and desiccation, limiting its field performance.

Shelf Life and Formulation Stability: Some formulations have short shelf lives, especially under improper storage conditions.

Variability in Field Performance: Efficacy may vary due to differences in soil type, moisture, pH, and cropping system.

Quality Control Issues: Inconsistent quality of commercial products due to unregulated production.

Limited Spectrum: Mainly effective against fungal pathogens; limited activity against insects and bacterial diseases.

Integration in IPM and Organic Farming

Trichoderma fits well into Integrated Pest Management (IPM) systems:

Efficacy against Major Pathogens

Pathogen/Disease	Host Crop	Trichoderma Species	Mode of Action
Fusarium oxysporum	Tomato, Banana	*T. harzianum, T. viride*	Mycoparasitism, ISR
Rhizoctonia solani	Rice, Cotton	*T. virens*	Competition, Antibiosis
Sclerotium rolfsii	Groundnut, Chillies	*T. asperellum*	Mycoparasitism
Pythium spp.	Vegetables	*T. harzianum*	Seed protection
Macrophomina phaseolina	Soybean, Maize	*T. viride*	Soil application

- ✓ Can be used alongside pheromone traps, resistant varieties, and botanical pesticides.
- ✓ Ideal for organic farming certifications due to its non-synthetic nature.
- ✓ Offers synergy when combined with arbuscular mycorrhizal fungi (AMF), biofertilizers, and neem-based products.

Future Prospects

Development of Climate-Resilient Strains: Focus on strains that perform well under stress conditions like drought or salinity.

Integration with Smart Farming: Use of drones and IoT for precise application of bioagents.

Global Expansion: Increasing adoption in Africa, Latin America, and Southeast Asia.

Policy Support: Governments promoting bio-inputs through subsidies and regulatory frameworks.

Conclusion

Trichoderma stands out as a potent, eco-friendly solution for pest and disease management in modern agriculture. Its multifaceted role ranging from biocontrol and growth promotion to soil health enhancement makes it a valuable asset in sustainable and organic farming systems. Though challenges in formulation, storage, and field application remain, ongoing research and technological innovations continue to enhance its effectiveness. Wider adoption of *Trichoderma* can significantly reduce the way for greener, safer, and more productive agricultural practices.

Urban Forest Creation Using the Miyawaki Model

Rajkumar Singh, Himanshu Trivedi and Ankit Singh Bhadauria

Introduction

Miyawaki method is an afforestation approach designed to create dense, fast-growing forests, developed by the late Japanese botany professor Akira Miyawaki. Starting in the 1970s, professor Miyawaki advocated the value of natural forests and the urgent need to restore them. His method turned theory to practice. Popping up more and more these days, especially in urban areas, Miyawaki Forests aim to provide a safe habitat for wildlife, as well as to contribute with several other important ecosystem services, such as cooling the surrounding environment, conserving water or contributing as significant carbon sequestration sinks. Also, these forests quickly become self-sustaining, typically requiring no maintenance after the first 3 years.

Benefits of Miyawaki Technique as Opposed to Normal Plantations

Miyawaki technique of growing forests is regarded as the most effective plantation method for quickly renewing degraded lands. Given below are the benefits of Miyawaki method of growing forests as opposed to normal plantation.

- ✓ Miyawaki technique is a unique methodology which comprises of pre-determined steps and procedures of planting trees. On the other hand, normal plantations do not have a set of defined procedure involving soil and site analysis, etc. which may prove to be a disadvantage in the development stages of a plant.
- ✓ The number of trees planted through Miyawaki technique are approximately 30 times more than the number of trees planted through traditional plantation technique. This is because as per the Miyawaki method, the sapling density is maintained at about 3 to 4 plant per sq. m. whereas normally, trees are planted with a spacing of at least 3 meters. Therefore, tree density per sq. m. is largely high in forests planted through the Miyawaki method as compared to normal plantation method.
- ✓ A minimum of 300 percent more species is found

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in the region where forest is regenerated through Miyawaki technique in comparison to the number of species found in conventional plantations. This can largely be attributed to the fact that high tree density along with a high nativity rate leads to rich biodiversity. A Miyawaki forest is thus a biodiverse region and provides habitat to a distinctive group of flora and fauna as compared to area with normal plantations.

- ✓ As opposed to traditional plantations, it has been found that there is a 3000 percent increase in noise and dust isolation in forests grown through the Miyawaki technique. Since the Miyawaki forests are dense in comparison to the normal plantations, they are able to mitigate noise and air pollution more effectively. Also, dust particles are less likely to sieve through a dense forest, as compared to normal plantations.

How to Develop a Miyawaki Forest: Steps Suggested by Dr. Akira Miyawaki

Development of Miyawaki forest involves an ecological engineering approach using the forest reconstruction method. The method is based on the knowledge of the following:

The potential natural vegetation of the site: Potential vegetation refers to "an abstract concept of a vegetation made up of the plant species present in remnants of the plant cover, without human influence''. A thorough analysis of the existing vegetation type, local topography and an understanding of inter and intra species relationships, as well as with the surrounding environment helps in determining the potential vegetation of the site. Information about the potential vegetation of a site is important to reconstruct a forest with native tree species that mimics the functioning of a natural forest.

Germination and establishment biology of seeds from specimen plants in a nursery: For the purpose of developing strong root systems to increase the rate of seedling survival in a forest, collection of seeds of the specimen plants which comprise the potential vegetation is important. This will help to ensure successful seed germination in the nursery. For this, seeds need to be sown in pots and after a period of two years, the seedlings should be planted at the actual site.

Procedure of planting of seedlings in a forest: The final procedure of planting seedlings in a forest includes the following steps:

Site preparation: This step involves the ploughing of soil on site to prepare the surface for planting of seedlings. Planting beds or low mounds of soil should be created to check harm caused due to flooding or heavy rains. In addition, mulching of planting beds with straws and organic fertilizer should be carried out to avoid potential damage to the seedlings.

Planting of seedlings: The process of planting seedlings in a forest is specifically ceremonious in nature in Japan and largely community-driven. This helps to install ecological values amongst the people as well as to develop a forest with a "complex

pattern of trees". Volunteers and participants should be guided to plant seedlings in pre-dug holes, followed by spreading of mulch around the planting mound.

Miyawaki Forest: Key Statistics

Planting Density:	3 to 7 trees per m2
Green Surface Area:	30 times more than a meadow
Survival rate (Natural Selection)	15% - 90%
Growth rate:	1.5 m year^{-1} (rainforest), 1 m year^{-1} (temperate forest), 0.3 m year^{-1} (Mediterranean forest)
Growth stabilization	From 15-20 years (temperate zone), 30-40 years (tropical zone)
Final average size	20 m (upper layer or emergent/canopy layer of a forest), 4 m (lower layer or understory)
Density after stabilization:	0.5 to 2.5 trees m^{-2}

Putting the method to practice

To achieve the ambitious goals set by Miyawaki, we try to mimic a natural forest environment by:

Enriching the existing soil: To jump-start the tree-growing process, we restore soil fertility by deeply decompacting the planting area and then adding large amounts of plant compost and well-composted animal manure. A generous application of mulch and the inoculation of added organic matter with beneficial mycorrhizal fungi are also essential.

Designing a multi-layered forest: A wide variety of species is planted to recreate the layers of a natural forest: the shrub layer (up to 2 meters), the sub-tree layer (2 to 4 m), the tree layer (4 to 12 m) and the canopy layer (above 12 m).

Planting very densely and at the same time

If planted together in a good environment, plants will benefit from density. This creates a protective effect and a competition for light which makes the trees grow very fast. It will also reduce evaporation. Normally, we're talking about a density of 3 trees m^{-2} in a minimum area of 10m².

Caring for and protecting all the baby trees: We keep the soil moist and weeds-free for the first 3 years. If we plant during the summer, we add a shade net, giving them a canopy-like protection, that also protects the plants from the wind.

Urban Forests: They are the Miyawaki method specialists in Europe and use the Miyawaki method to create urban forests. They believe that while it takes about 200 years to let a forest recover on its own, with the Miyawaki method a similar result is achieved in 20 years. The agency believes in creating a Miyawaki forest that grows each year by a minimum of 1 meter, without chemicals or synthetic fertilizers.

Given below are the steps followed by Urban Forests to create a Miyawaki forest:

Plantation: Seedlings are planted densely, 3 trees m^{-2} and randomly (not in line), mixing as many native trees of potential natural vegetation as possible.

Establishment of seedlings: Approximately three years after planting, natural selection among the seedlings allows the most adapted ones to develop quickly. After 15-20 years of planting, the early model of a dense mature forest gets established.

Maintenance and Monitoring: Site specific maintenance and monitoring needs to be undertaken for

two years, post plantation.

- ✓ Soil Analysis and Soil Preparation
- ✓ Determination of Native Species
- ✓ Floral Composition through Quadrat Survey
- ✓ Procurement of Saplings
- ✓ Preliminary Preparation for Plantation
- ✓ Undertaking Plantation
- ✓ Maintenance and Monitoring

Important Species for Miyawaki Forests

Shrub Layer (1-2 meters): These are short, bushy plants that support ground-level biodiversity.

Common Name	Botanical Name
Lemon Grass	*Cymbopogon citratus*
Tulsi (Holy Basil)	*Ocimum tenuiflorum*
Curry Leaf Plant	*Murraya koenigii*
Indian Jasmine	*Jasminum sambac*
Mehndi (Henna)	*Lawsonia inermis*

Tree Layer and Fruits Plants Layer (Above 2 meters): These trees form the upper canopy, providing shade, habitat, and contributing to the forest structure.

Common Name	Botanical Name
Neem	*Azadirachta indica*
Banyan	*Ficus benghalensis*
Peepal (Sacred Fig)	*Ficus religiosa*
Arjun	*Terminalia arjuna*
Kadamba	*Neolamarckia cadamba*
Kadulimba	*Melia dubia*
Karanja	*Pongamia pinnata*
Sita Ashoka	*Saraca asoca*
Jackfruit	*Artocarpus heterophyllus*
Mango	*Mangifera indica*
Guava	*Psidium guajava*
Tamarind	*Tamarindus indica*
Java Plum	*Syzygium cumini*
Pomegranate	*Punica granatum*
Bael (Wood Apple)	*Aegle marmelos*
Litchi	*Litchi chinensis*

Conclusion

The development of Miyawaki forests presents a powerful, scalable method for restoring native biodiversity and creating resilient, self-sustaining ecosystems in urban and degraded landscapes. By carefully selecting native species adapted to the local climate and soil, implementing high-density planting and encouraging stratification across multiple vegetation layers from shrubs to towering canopy trees Miyawaki forests rapidly establish complex habitats that support diverse flora and fauna. Adhering to best practices such as sourcing local seeds, preparing soil adequately, and ensuring proper initial care can significantly improve survival rates and forest health. Moreover, Miyawaki's emphasis on ecological restoration over mere plantation fosters greater carbon sequestration, mitigates urban heat, enhances soil quality and provides socio-economic benefits through ecosystem services.

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3G Cuttings: Simple Tool for Higher Yield in Cucurbits

Chandroday Prakash Tiwari, C. N. Ram, Aastik Jha and Shyam Prakash

Introduction

3G cutting is a simple cultural practice for achieving ultimate goal of higher yields for famers. It is being popular in Vegetable crops like- Tomato, Brinjal and other solanaceous vegetables but found highly successful and practically useful in Cucurbits like- Cucumber, Bottle Gourd, Ridge Gourd and Pumpkin etc. In simple terms, 3G stands for third generation in all crops. By trimming or pinching the first (primary) and second (secondary) branches off the plant, 3G cutting may be used to encourage the growth of 3rd generation (tertiary) branches. Following seed germination, only one main branch known as the first or fifth generation branch continues to grow. Second generation branches are those are produced by the main branch. Third generation branches are those that arise from any one of the initial second-generation branches. In all the cucurbits 1st and 2nd generation branches produced male and female flowers in ratio of 14:1 which gives impression of high flowering in plant but fruit setting remains low due to less female flowers. 3G cuttings promotes female flower initiation in plant as in 3 generation branches male and female ratio is reported 2:1, which further leads to better fruit setting and higher yield in cucurbits.

Importance and Practice: The development of fruits primarily depends on the female flowers, as they play a crucial role in fruit production. However, male flowers are also essential for pollination. Therefore, increasing the number of female flowers on a plant can lead to a higher yield of fruits. This is where the technique of 3G cutting comes into play, as it helps boost the number of pistillate (female) flowers on a plant. In many crops, the natural ratio of male to female flowers is imbalanced, with male flowers typically being more abundant. Observations have shown that after 3G cutting, the number of female flowers increases, sometimes equaling or surpassing the number of male flowers, which can significantly enhance crop production. For instance, in crops from the Cucurbitaceae family, the ratio of male to female flowers before 3G cutting is around 14:1, while after 3G cutting, the ratio shifts to 1:2, favouring higher fruit production.

The 3G cutting technique is practiced to increase the production of cucurbitaceous crops like gourds, cucumbers, pumpkins, and even other crops such as tomatoes, brinjal (eggplant) and okra. In India, agricultural universities and research institutes have been promoting 3G cutting, especially in states like Uttar Pradesh and Punjab, where farmers cultivate cucurbits extensively. In Nepal farmers has also adopted this method in its efforts to boost small-scale farming, given the country's reliance on cucurbit crops for both domestic consumption and

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local markets

Objective of 3G Cutting

Main objective of 3G cutting is to make balance between male and female flowers in cucurbits. It makes balance the ratio between male and female flower ratio in cucurbits. Higher number of female flowers is essential for higher fruit set. However male flower is also important in relation to yield. One male (Staminate) flower can fertilize many female flowers (Pistillate) but it is female flower which is necessity for fruit set. Farmers use chemicals in abundance for higher yield which can be reduced with this basic interculture operation. With use of 3G cutting in cucurbits adds benefits to the yield with simple interculture operation, which requires little precision.

Procedure of 3G cutting

3G cutting in cucurbits is a simple interculture operation requires basic steps with a bit technical precision:

- ✓ Allow main (Primary) branch to grow uninterrupted with proper care and maintenance till it attain a height of 6-7 feet.
- ✓ When main branch attains height of 7 to 8 feet, apical portion of the plant about 4-5 inch should be removed.
- ✓ Removal of apical portion promotes initiation of secondary branch formation in the plant due to translocation of food reserve to the secondary branch.
- ✓ Same as the previous one, tip portion (4-5 inch) of the secondary branch should be removed after it grows 3 to 4 feet. This action promotes the initiation of the tertiary branch or 3rd generation branch.
- ✓ This 3rd generation (3G) branch is heavy bearer and allowed to be grow for the high production as it blossoms with high female flower

Advantages

The 3G cutting technique is a newly developed method in agriculture, and researchers have observed remarkable results from its application. This technique can significantly enhance crop production, especially in organic farming systems, making it a valuable tool for farmers. By increasing the number of female flowers per plant, the likelihood of fruit set also rises, leading to improved yields. Additionally, the quality and size of the fruits are superior, which is beneficial for farmers with small land holdings, as it helps them generate more income from limited space. Moreover, the overall increase in production directly translates into higher net profits, contributing to the better livelihoods of rural farmers. One of the key advantages of 3G cutting is that it boosts yield without requiring significant additional investment, aside from the need for skilled labor on larger farms. Furthermore, this technique aids in the proper training of gourd, melon, pumpkin, and cucumber plants, ensuring that each vine receives adequate sunlight for photosynthesis, thus promoting optimal growth and development.

Challenges in 3G cutting

Despite its broad benefits 3G cuttings have its

own challenges that should have to be in mind while planning this practice to perform:

- ✓ It requires more labours with technical knowledge
- ✓ It needs regular attention and inspection which is tedious work
- ✓ Cutting leads to disease and infection if no proper cure given at right time
- ✓ Production time slight delay

Conclusion

3G cutting is benefiting cultural practice and can be a great asset in higher production of certain crops. It applicable in various crops like- Tomato, Brinjal, Chilli and Okra etc. but it has more significant and positive response in Cucurbitaceous crops. Apart from its few challenges it is simple and highly useful technique in increasing yield of crop.

Protein Modelling in Agriculture: Unlocking the Secrets of Plant Proteins

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Abstract

Protein modelling is an emerging approach in agricultural research that provides insights into the three-dimensional structures and functions of plant proteins. By leveraging computational techniques such as homology modelling, ab initio modelling, molecular docking, and machine learning tools like AlphaFold, scientists can predict protein structures to understand their role in crop growth, nutrition, stress tolerance, and disease resistance. This knowledge facilitates the development of nutrient-rich and climate-resilient crops, improves plant-based food products, and supports sustainable agricultural practices. Real-world applications include engineering seed storage proteins for enhanced digestibility, modelling protein-protein interactions for disease resistance and designing enzymes for improved nutrient bioavailability. As computational biology continues to advance, protein modelling will play a vital role in modern agriculture, bridging the gap between molecular insights and practical crop improvement strategies.

Introduction

Agriculture has always been the backbone of human civilization, and in the modern era, science and technology are playing a pivotal role in enhancing crop production and quality. Among the various scientific approaches, protein modelling has emerged as a powerful tool to understand plant proteins at the molecular level, opening new avenues for crop improvement, disease resistance, and better food products. This article provides an easy-to-understand overview of protein modelling in agriculture, its applications, and its future potential.

What is Protein Modelling?

Proteins are the workhorses of all living organisms, carrying out crucial functions such as catalyzing biochemical reactions, providing structural support, and facilitating communication between cells. Protein modelling refers to the computational prediction and visualization of the three-dimensional (3D) structure of proteins based on their amino acid sequences.

Since the function of a protein largely depends on its structure, predicting these structures helps scientists understand how proteins work. There are three primary methods of protein modelling:

Homology (Comparative) Modelling: Uses the structure of a similar known protein as a template.

Ab Initio Modelling: Predicts the structure from scratch using physical and chemical principles.

Molecular Docking and Dynamics: Simulates how proteins interact with other molecules over time.

With the advent of machine learning tools

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like AlphaFold, the accuracy of protein structure prediction has reached unprecedented levels, making protein modelling more accessible and useful for agricultural research.

Importance of Protein Modelling in Agriculture

In agriculture, understanding plant proteins is crucial because they determine traits like growth, stress tolerance, disease resistance, and nutritional quality. Protein modelling offers several benefits:

Crop Improvement

- ✓ By modelling seed storage proteins such as glutelins and prolamins, breeders can identify structural features that influence nutritional value and digestibility.
- ✓ For example, improving the structure of proteins in legumes can enhance protein availability in plant-based diets.

Plant Disease Resistance

- ✓ Proteins are central in plant-pathogen interactions. Protein-protein interaction (PPI) modelling helps in understanding how pathogens attack and how plants defend themselves.
- ✓ This knowledge can be used to design disease-resistant crop varieties.

Stress Tolerance: Crops often face drought, salinity, and temperature stress. Modelling stress-response proteins (like heat-shock proteins) can help develop climate-resilient crops.

Food Industry Applications: Protein modelling aids in designing plant proteins with better solubility, texture, and functionality, which is essential for plant-based foods, dairy alternatives, and bakery products.

Case Studies in Agricultural Protein Modelling

Rice Seed Storage Proteins: Computational modelling has helped improve the digestibility of rice proteins and reduce allergenicity.

Wheat Gluten Proteins: Understanding the 3D structure of gluten proteins assists in breeding wheat with desired baking properties.

Plant Enzyme Engineering: Docking simulations have been used to modify enzymes that improve nutrient bioavailability in crops.

Future Prospects

The future of protein modelling in agriculture looks promising with the integration of AI-driven tools, omics technologies, and biotechnology. Potential developments include:

- ✓ Precision breeding for high-protein crops.
- ✓ Engineering proteins for biofortification to combat malnutrition.
- ✓ Development of biodegradable plant-based materials using structural insights.

Conclusion

Protein modelling is revolutionizing agricultural research by providing a molecular-level understanding of plant proteins. From enhancing crop nutrition to building climate-resilient varieties and supporting the plant-based food industry, its applications are vast and impactful. As computational biology continues to advance, protein modelling will play a central role in creating sustainable and innovative agricultural solutions.

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Insect and Disease Management of Urd (Black Gram)

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Abstract

Urd bean, commonly known as black gram, is a vital pulse crop cultivated extensively in India for its high protein content and soil-enriching properties. However, its productivity is significantly affected by various insect pests such as aphids, whiteflies, pod borers, and jassids, as well as diseases like Yellow Mosaic Virus (YMV), Cercospora leaf spot, powdery mildew, root rot, and anthracnose. These pests and diseases not only reduce yield but also deteriorate grain quality. Effective management involves the adoption of Integrated Pest and Disease Management (IPDM) strategies, which include the use of resistant varieties, timely sowing, crop rotation, field sanitation, seed treatment with fungicides and biocontrol agents, and the application of need-based chemical and botanical pesticides. Biological control through natural enemies and microbial formulations is also encouraged to minimize environmental hazards. Regular monitoring and early detection play a crucial role in reducing economic losses. The integration of cultural, biological, and chemical methods in a sustainable framework ensures effective control of pests and diseases while safeguarding crop health and environmental safety.

Introduction

Urd bean (*Vigna mungo*), commonly known as black gram, is a significant pulse crop cultivated mainly in India for its high protein content and soil-enriching properties. However, its production is seriously hampered by several insect pests and diseases, which cause considerable yield losses. Integrated Pest and Disease Management (IPDM) plays a vital role in sustaining urd bean productivity under diverse agro-ecological conditions. The following is a comprehensive and detailed explanation of the insect and disease management practices in urd cultivation:

Insect Pest Management in Urd

Aphids (*Aphis craccivora*)

Nature of Damage: Nymphs and adults suck the cell sap from tender parts of the plant including leaves, buds, and flowers. They also secrete honeydew, which promotes sooty mold growth and inhibits photosynthesis.

Symptoms: Curling and yellowing of leaves, reduced plant vigor, and black sooty mold on leaves and pods.

Management

Cultural: Timely sowing, use of resistant varieties, removal of alternate weed hosts.

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Biological: Release of *Chrysoperla zastrowi* and *Coccinella septempunctata* (ladybird beetle).

Chemical: Spraying with Dimethoate 30 EC @ 1.5 ml litre^{-1} or Imidacloprid 17.8 SL @ 0.3 ml litre^{-1}.

Whitefly (*Bemisia tabaci*)

Nature of Damage: Sucks sap from the lower surface of leaves and also transmits Yellow Mosaic Virus (YMV).

Symptoms: Chlorotic patches, reduced photo-synthesis, and downward curling of leaves.

Management

Cultural: Timely sowing and removal of virus-infected plants.

Biological: *Encarsia formosa* and *Trialeurodes* spp.

Chemical: Spraying Thiamethoxam 25 WG @ 0.25 g litre^{-1} or Acetamiprid 20 SP @ 0.2 g litre^{-1}.

Pod Borer (*Helicoverpa armigera*)

Nature of Damage: Larvae bore into buds, flowers, and developing pods, feeding on seeds inside.

Symptoms: Holes in pods, with excreta around entry points.

Management

Cultural: Intercropping with sorghum or maize, timely sowing.

Biological: Release of *Trichogramma chilonis* @ 50,000 ha^{-1} weekly.

Chemical: Spray Spinosad 45 SC @ 0.3 ml litre^{-1} or Emamectin benzoate 5 SG @ 0.4 g litre^{-1}.

Jassids (*Empoasca kerri*)

Nature of Damage: Nymphs and adults suck sap from the undersides of leaves.

Symptoms: Leaf curling, yellowing, and necrotic patches.

Management

Cultural: Use of tolerant varieties and crop rotation.

Chemical: Spray Monocrotophos 36 SL @ 1.5 ml litre^{-1} or Imidacloprid 17.8 SL @ 0.3 ml litre^{-1}.

Bihar Hairy Caterpillar (*Spilosoma obliqua*)

Nature of Damage: Young larvae scrape the leaf surface; older larvae consume the entire foliage.

Symptoms: Skeletonized leaves, severe defoliation.

Management

Mechanical: Hand-picking of early instar larvae.

Chemical: Spray Chlorantraniliprole 18.5 SC @ 0.3 ml litre^{-1} or Quinalphos 25 EC @ 2 ml litre^{-1}.

Disease Management in Urd

Yellow Mosaic Virus (YMV)

Causal Agent: Mungbean yellow mosaic virus (transmitted by whitefly).

Symptoms: Yellow patches on leaves, stunted growth, poor flowering, and shriveled pods.

Management

Cultural: Grow resistant varieties like ‘Pant U 19’, ‘T 9’, ‘LBG 752’.

Sanitation: Remove and destroy infected plants.

Vector Management: Spray Imidacloprid 17.8 SL @ 0.3 ml litre^{-1} or Thiamethoxam 25 WG @ 0.25 g litre^{-1} at early crop stage.

Biological: Conservation of natural enemies like *Encarsia formosa* for whitefly control.

Cercospora Leaf Spot (*Cercospora canescens, C. cruenta*)

Symptoms: Small, circular to irregular brown spots with gray centers on leaves, stems, and pods.

Favorable Conditions: High humidity and moderate temperature.

Management

Cultural: Crop rotation, field sanitation, resistant varieties like 'LBG 20', 'LBG 402'.

Chemical: Spray Carbendazim 50 WP @ 1 g litre^{-1} or Mancozeb 75 WP @ 2 g litre^{-1} at 10-15-day intervals.

Botanical: Neem leaf extract (5%) can also be sprayed as a preventive measure.

Powdery Mildew (*Erysiphe polygoni*)

Symptoms: White powdery fungal growth on upper leaf surfaces, leading to premature defoliation.

Favorable Conditions: Warm and dry conditions.

Management

Cultural: Avoid dense planting; ensure good air circulation.

Chemical: Spray Sulphur 80 WP @ 2 g litre^{-1} or Hexaconazole 5 EC @ 1 ml litre^{-1}.

Organic: Spray with diluted cow milk (1:10 ratio) or use potassium bicarbonate @ 5 g litre^{-1} as a safer alternative.

Root Rot and Wilt (*Macrophomina phaseolina, Fusarium spp.*)

Symptoms: Sudden wilting of plants, yellowing, and black rotting of roots; stem may show discolouration.

Favorable Conditions: High soil temperature, drought conditions.

Management

Seed Treatment: Use *Trichoderma viride* @ 4 g kg^{-1} seed or Carbendazim + Thiram @ 2 g kg^{-1} seed.

Soil Amendment: Application of neem cake @ 200 kg ha^{-1} before sowing.

Crop Rotation: Avoid monocropping of pulses.

Anthracnose (*Colletotrichum lindemuthianum*)

Symptoms: Circular dark brown to black lesions with concentric rings on pods, stems, and petioles.

Management

Seed Treatment: Carbendazim or Thiram @ 2 g kg^{-1}.

Foliar Spray: Carbendazim 50 WP @ 1 g litre^{-1} at early disease appearance.

Integrated Disease and Insect Management Strategy for Urd

Use of Resistant Varieties: Use of genetically resistant/tolerant varieties reduces chemical dependency and ensures stable yields.

Timely Sowing: Early sowing (*Kharif* - early July; *Rabi* - late October) helps escape peak pest and disease periods.

Seed Treatment

Fungicide: Thiram + Carbendazim @ 2 g kg^{-1} seed.

Biopesticide: *Trichoderma viride* @ 4 g kg^{-1} seed.

Cultural Practices

- ✓ Crop rotation with cereals (e.g., maize, wheat).
- ✓ Adequate plant spacing and good drainage to avoid disease build-up.

Botanical and Biocontrol Agents

- ✓ Use neem-based pesticides (NSKE 5% or neem oil @ 5 ml litre^{-1}).
- ✓ Use of *Trichogramma chilonis*, *Chrysoperla carnea*, *Bacillus thuringiensis*.

Chemical Sprays (only as last resort)

- ✓ Use selective and low-residual insecticides/

fungicides.

- ✓ Follow proper waiting periods before harvest.

Monitoring and Forecasting

- ✓ Regular field scouting for pest thresholds.
- ✓ Installation of yellow sticky traps for whiteflies and aphids.

Conclusion

Effective insect and disease management in urd (black gram) requires a holistic approach combining preventive measures, resistant varieties, biological controls, and judicious use of chemicals. Adoption of IPM practices not only ensures sustainable yield and quality of the crop but also contributes to environmental protection and farmer profitability. The integration of agronomic practices with ecological pest regulation mechanisms is the key to long-term pest and disease suppression in urd cultivation.

Insect and Disease Management of Groundnut (*Arachis hypogaea*)

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Abstract

Groundnut a vital oilseed and food legume crop, is widely cultivated in tropical and subtropical regions. Despite its economic and nutritional importance, groundnut productivity is significantly constrained by various insect pests and diseases. Major insect pests include aphids, thrips, jassids, leaf miners, white grubs, red hairy caterpillars, and pod borers, which damage different plant parts, reducing yield and quality. Important diseases affecting groundnut are tikka leaf spots, rust, collar rot, stem rot, bud necrosis disease, and viral infections such as peanut stripe virus. Effective management of these biotic stresses requires an Integrated Insect and Disease Management (IIDM) approach, incorporating resistant varieties, seed treatment with fungicides and insecticides, timely sowing, crop rotation, intercropping, and appropriate soil and water management. Use of biological agents such as *Trichoderma spp.*, *Metarhizium anisopliae*, and natural enemies like ladybird beetles, combined with neem-based botanicals and need-based chemical control, ensures sustainable and eco-friendly pest suppression. Regular monitoring and early intervention further enhance effectiveness. The adoption of IIDM strategies is essential for maximizing groundnut productivity, profitability, and environmental sustainability.

Introduction

Groundnut (*Arachis hypogaea*), also known as peanut, is an economically important oilseed crop grown in tropical and subtropical regions for its edible seeds and oil content. It also improves soil fertility through symbiotic nitrogen fixation. However, groundnut cultivation is frequently challenged by a wide range of insect pests and diseases, which can cause significant yield and quality losses. A comprehensive and integrated approach is essential for effective management to ensure profitable and sustainable cultivation.

Insect Pest Management in Groundnut

Aphids (*Aphis craccivora*)

Nature of Damage

- ✓ Nymphs and adults suck sap from tender leaves and stems, causing yellowing, curling, and stunting.
- ✓ Also act as vectors for Peanut Stripe Virus and other viral diseases.

Management

Biological Control: Encourage predators like ladybird beetles (*Coccinella spp.*) and green lacewings.

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Botanical: Spray Neem Seed Kernel Extract (NSKE 5%).

Chemical: Imidacloprid 17.8 SL @ 0.3 ml litre^{-1} or Thiamethoxam 25 WG @ 0.25 g litre^{-1}.

Thrips (*Scirtothrips dorsalis, Frankliniella spp.*)

Nature of Damage: Suck cell sap from young leaves, resulting in silvery appearance and leaf crinkling.

Management

Cultural: Early sowing, optimum plant spacing.

Chemical: Spray Fipronil 5 SC @ 1.5 ml litre^{-1} or Acephate 75 SP @ 1 g litre^{-1}.

Jassids or Leafhoppers (*Empoasca kerri*)

Nature of Damage: Sap-sucking pest causing characteristic yellowing at leaf margins, "hopper burn," and reduced photosynthesis.

Management

Botanical: NSKE 5%.

Chemical: Spray Dimethoate 30 EC @ 2 ml litre^{-1} or Acetamiprid 20 SP @ 0.25 g litre^{-1}.

White Grubs (*Holotrichia spp.*)

Nature of Damage: Grubs feed on roots and underground pods, causing plant wilting and pod damage.

Management

Cultural: Deep ploughing after harvest to expose grubs.

Soil Application: Chlorpyrifos 20 EC @ 2 litres ha^{-1} in 250 kg FYM during last ploughing.

Biological Control: Apply *Metarhizium anisopliae* @ 2.5 kg ha^{-1}.

Red Hairy Caterpillar (*Amsacta albistriga*)

Nature of Damage: Gregarious feeders in early instars; severe defoliation.

Management

Mechanical: Light traps and hand collection.

Chemical: Spray Quinalphos 25 EC @ 2 ml litre^{-1}.

Leaf Miner (*Aproaerema modicella*)

Nature of Damage: Larvae mine leaves forming brown blotches and feeding inside.

Symptoms: Skeletonized leaves with dead patches.

Management

Biological: Use parasitoids like *Stenomesius japonicus*.

Chemical: Spray Chlorantraniliprole 18.5 SC @ 0.4 ml litre^{-1} or Spinosad 45 SC @ 0.3 ml litre^{-1}.

Gram Pod Borer (*Helicoverpa armigera*)

Nature of Damage: Bores into pods and feeds on developing seeds.

Management

Biological: Release *Trichogramma chilonis* @ 50,000 ha^{-1} week^{-1}.

Chemical: Spray Emamectin benzoate 5 SG @ 0.4 g litre^{-1} or Indoxacarb 14.5 SC @ 1 ml litre^{-1}.

Disease Management in Groundnut

Tikka Disease (Early and Late Leaf Spot)

Causal Organisms

- ✓ *Cercospora arachidicola* (early leaf spot)
- ✓ *Phaeoisariopsis personata* (late leaf spot)

Symptoms: Dark brown to black circular spots on leaves; early defoliation and yield loss.

Favorable Conditions: High humidity, cloudy weather.

Management

Resistant Varieties: ICGV 86699, GG 2.

Seed Treatment: Thiram or Mancozeb @ 3 g kg^{-1} seed.

Fungicide Spray: Mancozeb 75 WP @ 2 g $litre^{-1}$ or Chlorothalonil @ 2 g $litre^{-1}$ at 30, 60, and 90 DAS.

Rust (*Puccinia arachidis*)

Symptoms: Small reddish-brown pustules on the underside of leaves, later coalescing to cause severe defoliation.

Management

Fungicide: Spray Hexaconazole 5 EC @ 1 ml $litre^{-1}$ or Propiconazole 25 EC @ 1 ml $litre^{-1}$.

Collar Rot (*Aspergillus niger, A. flavus*)

Symptoms: Seedlings collapse and die due to rotting at collar region.

Favorable Conditions: High soil moisture, poor drainage.

Management

Seed Treatment: Thiram + Carbendazim @ 2 g kg^{-1} each.

Soil Treatment: Application of *Trichoderma viride* @ 4 kg ha^{-1} mixed with FYM.

Stem Rot (*Sclerotium rolfsii*)

Symptoms: Yellowing, drooping, and rotting at stem base; presence of white mycelium and brown sclerotia.

Management

Crop Rotation: Avoid groundnut monoculture.

Soil Application: *Trichoderma harzianum* @ 2.5 kg ha^{-1}.

Chemical: Spray Carbendazim 50 WP @ 1 g $litre^{-1}$.

Bud Necrosis Disease (BND)

Causal Agent: Groundnut Bud Necrosis Virus (GBNV), transmitted by thrips.

Symptoms: Necrosis of terminal buds, stunted growth, ring spots on leaves.

Management

Vector Control: Spray Imidacloprid 17.8 SL @ 0.3 ml $litre^{-1}$ or Fipronil 5 SC @ 1.5 ml $litre^{-1}$.

Resistant Varieties: ICGV 86031, ICGS 11.

Peanut Stripe Virus (PStV)

Symptoms: Mottling, striping on leaves, and reduced pod set.

Management

Vector Control: Manage aphids using systemic insecticides.

Seed Selection: Use certified virus-free seed.

Integrated Insect and Disease Management (IIDM) in Groundnut

Resistant Varieties

- ✓ Cultivate varieties resistant to tikka leaf spot, rust, collar rot, and bud necrosis.
- ✓ Examples: ICGV 91114, TAG 24, GG 5, ICGV 86699.

Seed Treatment

Treat seeds with:

- ✓ Thiram + Carbendazim @ 3 g kg^{-1}
- ✓ Imidacloprid 70 WS @ 5 g kg^{-1}
- ✓ *Trichoderma harzianum* @ 4 g kg^{-1} (for biological protection)

Timely Sowing: Sowing at the onset of monsoon ensures healthy crop stand and reduced pest incidence.

Crop Rotation and Intercropping

- ✓ Rotate with cereals like sorghum or maize to break disease cycles.
- ✓ Intercropping with castor or maize helps reduce insect pest population.

Soil and Water Management

- ✓ Ensure proper drainage to avoid collar and stem rot.
- ✓ Use gypsum to correct calcium deficiency and improve pod filling.

Biological Control

Use of bioagents such as:

- ✓ *Trichoderma* spp. for collar rot and stem rot
- ✓ *Metarhizium anisopliae* for white grubs
- ✓ *NPV* and *Bacillus thuringiensis* for pod borers

Botanical Control: NSKE 5% or neem oil 5 ml/litre for aphids, jassids, and early-stage larvae.

Chemical Control

- ✓ Apply insecticides and fungicides judiciously based on Economic Threshold Levels (ETLs).
- ✓ Rotate chemical groups to prevent resistance development.

Monitoring and Surveillance

- ✓ Install pheromone traps and light traps.
- ✓ Conduct weekly field scouting to detect early pest and disease symptoms.

Conclusion

Groundnut is susceptible to numerous insect pests and diseases throughout its growth cycle. Effective management depends on a holistic and integrated approach, combining cultural practices, resistant varieties, seed and soil treatment, biological agents, botanical pesticides, and judicious use of chemicals. Emphasis should be placed on eco-friendly methods and early detection to minimize losses. Adoption of Integrated Insect and Disease Management (IIDM) not only enhances productivity and profitability but also promotes environmental sustainability and long-term soil health in groundnut farming systems.

Insect and Disease Management of Maize

S. G. Ghugal and Shakshi Singh

Abstract

Maize is a major cereal crop grown worldwide for food, fodder, and industrial use. Its productivity, however, is significantly affected by a wide range of insect pests and diseases at various growth stages. Key insect pests include fall armyworm (*Spodoptera frugiperda*), stem borers (*Chilo partellus*, *Sesamia inferens*), shoot fly (*Atherigona spp.*), aphids, and thrips, which cause damage through defoliation, boring, sap sucking, and destruction of reproductive parts. Major diseases such as Turcicum leaf blight (*Exserohilum turcicum*), Maydis leaf blight (*Bipolaris maydis*), downy mildew (*Peronosclerospora sorghi*), banded leaf and sheath blight (*Rhizoctonia solani*), and ear rots significantly reduce photosynthetic activity, grain development, and overall yield. Effective management requires an Integrated Pest and Disease Management (IPDM) strategy that combines cultural practices (timely sowing, crop rotation, resistant varieties), seed treatments, mechanical removal, biological control agents (e.g., *Trichogramma*, *Trichoderma*, NPV, *Beauveria*), and need-based chemical control based on economic threshold levels. Timely implementation of IPDM practices enhances maize productivity while minimizing environmental and economic risks, ensuring sustainable crop production.

Introduction

Maize (*Zea mays* L.), also known as corn, is one of the most widely cultivated cereal crops in the world, used for food, feed, fodder, and industrial purposes. In India, maize is grown in both *kharif* and *rabi* seasons across various agro-climatic zones. Despite its high yield potential, maize production is significantly constrained by a range of insect pests and diseases that affect the crop at different growth stages, leading to yield and quality losses. Proper identification and timely management of these pests and diseases are essential for maximizing productivity. This answer elaborates on the major insect pests and diseases of maize, their symptoms, nature of damage, and integrated management strategies.

Insect Pests of Maize

Fall Armyworm (*Spodoptera frugiperda*)

Nature of Damage

- ✓ Larvae feed voraciously on leaves, whorls, tassels, and ears.
- ✓ Most damaging during seedling to vegetative stages.

Symptoms

- ✓ Ragged leaves with large holes.

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- ✓ Presence of larvae and frass in whorls.
- ✓ Dead heart in young plants.

Management

Monitoring: Use pheromone traps @ 5 traps ha^{-1}.

Cultural: Timely sowing, intercropping with legumes.

Mechanical: Hand-picking of larvae in small fields.

Biological: Release *Trichogramma pretiosum*, spray *Metarhizium anisopliae* or *Beauveria bassiana*.

Chemical: Spray Spinosad 45% SC @ 0.5 ml l^{-1} or Chlorantraniliprole 18.5% SC @ 0.4 ml l^{-1} in whorl.

Stem Borer (*Chilo partellus*)

Nature of Damage: Larvae bore into stem and feed on internal tissues.

Symptoms

- ✓ Pinholes on leaves, dead heart in young plants.
- ✓ Tunneling in stem reduces plant strength and grain filling.

Management

Cultural: Deep ploughing to expose pupae.

Biological: Release *Trichogramma chilonis* @ 50,000 ha^{-1}.

Chemical: Spray Carbofuran 3G @ 10 kg ha^{-1} in whorl or Lambda-cyhalothrin 5% EC @ 1 ml l^{-1}.

Pink Stem Borer (*Sesamia inferens*)

Nature of Damage: Similar to *Chilo partellus* but more severe in *rabi* maize.

Symptoms: Dead heart, withering leaves, and stem tunneling.

Management

Cultural: Destruction of crop residue and stubbles.

Chemical: Use Fipronil 5% SC @ 2 ml $liter^{-1}$.

Shoot Fly (*Atherigona spp.*)

Nature of Damage: Larvae cut the central growing point in seedlings.

Symptoms: Dead heart during early stages; chaffy panicles in later stages.

Management

Cultural: Early sowing, optimum plant spacing.

Seed Treatment: Use Imidacloprid 600 FS @ 5 ml kg^{-1} seed.

Chemical: Spray Dimethoate 30% EC @ 2 ml $liter^{-1}$.

Aphids and Thrips

Nature of Damage: Suck sap from leaves, leading to chlorosis, curling, and stunted growth.

Symptoms: Yellow patches, distorted leaves, sticky honeydew, and sooty mold.

Management

Biological: Encourage predators like ladybird beetles.

Chemical: Spray Thiamethoxam 25% WG @ 0.25 g l^{-1} or Imidacloprid 17.8% SL @ 0.3 ml l^{-1}.

Major Diseases of Maize

Turcicum Leaf Blight (*Exserohilum turcicum*)

Symptoms

- ✓ Elongated, cigar-shaped, brown to gray necrotic lesions on leaves.
- ✓ Severe infection reduces photosynthetic area and grain filling.

Favorable Conditions: High humidity and moderate temperatures.

Management

Cultural: Grow resistant varieties like HQPM-1,

BIO 9637.

Chemical: Spray Mancozeb 75% WP @ 2.5 g l^{-1} or Propiconazole 25% EC @ 1 ml l^{-1}.

Maydis Leaf Blight (*Bipolaris maydis*)

Symptoms

- ✓ Small elliptical tan lesions with dark brown margins on leaves.
- ✓ Coalescence of lesions leads to premature drying.

Management

Cultural: Field sanitation and crop rotation.

Chemical: Spray Chlorothalonil or Carbendazim + Mancozeb.

Downy Mildew (*Peronosclerospora sorghi*)

Symptoms

- ✓ Yellowing and white downy growth on underside of leaves.
- ✓ Stunted growth, twisted leaves, and barren plants.

Management

Seed Treatment: Use Metalaxyl 35% WS @ 2 g kg^{-1} seed.

Chemical: Spray Metalaxyl + Mancozeb @ 2.5 g $liter^{-1}$.

Banded Leaf and Sheath Blight (*Rhizoctonia solani*)

Symptoms

- ✓ Concentric banded lesions on lower leaves and sheaths.
- ✓ Rots sheath and stem, causing lodging.

Management

Cultural: Avoid water stagnation; improve drainage.

Chemical: Spray Validamycin 3% L @ 2 ml $liter^{-1}$.

Charcoal Rot (*Macrophomina phaseolina*)

Symptoms

- ✓ Darkened root and stalk tissue with black sclerotia.
- ✓ Plant wilting at grain filling stage.

Management

Cultural: Avoid drought stress and nutrient imbalance.

Biological: Apply *Trichoderma viride* @ 2.5 kg ha^{-1}.

Seed Treatment: Carbendazim @ 2 g kg^{-1}.

Common Rust (*Puccinia sorghi*)

Symptoms

- ✓ Reddish-brown pustules on leaves.
- ✓ Severe infection reduces photosynthetic efficiency.

Management

Chemical: Spray Propiconazole or Hexaconazole @ 1 ml l^{-1}.

Fusarium Ear Rot (*Fusarium moniliforme*)

Symptoms

- ✓ Whitish-pink fungal growth on kernels.
- ✓ Grains become light, shriveled, and moldy.

Management

Cultural: Harvest at physiological maturity; dry grains properly.

Chemical: Seed treatment with Captan @ 2 g kg^{-1}.

Important Seed Treatments for Maize

- ✓ Metalaxyl 35% WS @ 2 g kg^{-1} for downy mildew.
- ✓ Carbendazim 50% WP @ 2 g kg^{-1} for ear rot,

stalk rot.

- ✓ Imidacloprid 600 FS @ 5 ml kg^{-1} for early-stage sucking pests.
- ✓ *Trichoderma viride* @ 4 g kg^{-1} for biological protection.

Integrated Pest and Disease Management (IPDM) in Maize

Component	Management Practice
Cultural Practices	Timely sowing, deep ploughing, clean cultivation, crop rotation, intercropping
Seed Treatment	With fungicides (Carbendazim, Metalaxyl) and insecticides (Imidacloprid)
Mechanical Control	Hand removal of larvae, collection and destruction of infected plant debris
Biological Control	Use of *Trichoderma*, *Pseudomonas fluorescens*, parasitoids, *Beauveria bassiana*, NPV
Chemical Control	Judicious use of insecticides and fungicides based on ETL
Monitoring Tools	Pheromone traps for *Spodoptera*, light traps, disease scouting

Conclusion

Insect pests and diseases pose a serious threat to maize productivity across all stages of growth, from seedling to maturity. An effective Integrated Pest and Disease Management (IPDM) approach, involving proper diagnosis, timely monitoring, cultural and mechanical methods, biological controls, and need-based chemical interventions, is essential for minimizing losses. Adoption of IPDM not only protects yield and crop health but also promotes environmentally sustainable maize farming, particularly important in the face of climate variability and pesticide resistance.

An Apprise: Harmful and Beneficial Traits of *Parthenium hysterophorus*

Devendra Kumar Meena, Banwari Lal Jat, Akashay Chittora and Sunita Kumari

Introduction

It is believed to have originated in North America and was introduced to India and Australia in the 1950s, in right now we are confronting the pervasion of *Parthenium hysterophorus* all over the place. It is accessible in stocks around the rail route tracks, in exposed lands, in farming fields, in plantations and in backwoods, it attacks significant part of Indian mainland. Weeds in routine are known to be undesirable in a given circumstance and these are hurtful, perilous or monetarily impeding having serious danger to essential creation and biodiversity. Obtrusive Outsider Species are known to be the species which are presented from outside from its starting point spot to different nations either by purposely or accidental human exercises. They have laid out self-duplicating populaces in the wild and have caused apparent changes in adjacent, reproduced as well as natural frame works. Intrusion is known as vital danger to biodiversity. They lessen ranch and woodland efficiency. *Parthenium hysterophorus* is the really obtrusive outsider weed which rules over the local species and antagonistically influences the biodiversity. The word Parthenium is taken from the Latin word parthenice which implies for restorative purposes *Parthenium hysterophorus* is an intrusive weed plant of family Asteraceae. This erect, brief plant known for its flourish development and its overflow remarkably in blistering environments. Parthenium is local plant of north-east Mexico and was endemic to America however presently it is broadly dispersed in all nations of Asia and Europe. Parthenium (*Parthenium hysterophorus* L.) is known with various names in various nations, for example, carrot weed, star weed, congress grass, wild feverfew, ragweed, harsh weed, white top. This weed with useful seed age affects adjoining plants and seriousness with monetarily significant yields.

In India: *Parthenium hysterophorus* potentially entered India in 1910 (with contaminated grains germplasm) be that as it may, went unrecorded until 1956. The weed was first uncovered in Quite a while in 1955 and presently happens wherever the in around 35 million hectares of land. In India, this weed has difficult issue in surmised all states like Karnataka, Andhra Pradesh, Haryana, Bihar, Madhya Pradesh and Uttar-Pradesh. Parthenium hysterophorus happened in all conditions of nation and introducing a serious danger in many states those

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have huge areas of farming area, non-editing regions and touching area. At present time India has becomes one of the most plagued nations of world.

How it is spreads: *Parthenium hysterophorus* hold a remarkable ability to spread develop and laid out well in extensive variety of natural circumstances. It finishes life-cycle 90-120 days which helps in speedy spreading. Its seeds can be scattered through different techniques like water ebb and flow, creatures, development of vehicles, hardware, animals and the grains or seeds of harvests. Further Parthenium has a somewhat short life cycle, develops rapidly and makes due under various territories. By and large for significant distances it spread through vehicle, farming instruments and with water stream. Parthenium created huge number of minuscule seeds which are light weight and can make due as seed bank in soil for long time. These a few capacities of *Parthenium hysterophorus* assists with spreading quickly brought about invasion of Parthenium all over the place.

Infestation of *Parthenium hysterophorus*: Before 1980 this week was only from time to time saw filling in crop lands however presently it has spread a lot of degree into practically a wide range of farming harvests, woodlands and manor biological systems. In Uttar-Pradesh, Uttarakhand, Andhra Pradesh, Karnataka, Madhya Pradesh, Maharashtra and so on, Parthenium is known as unsafe weed of agribusiness lands. In crop fields, where just a single harvest is filled in a year, it fills richly in the neglected period following the event of gentle down-pours. Its pervasion is extreme in the field where water system channels are utilized. On the bank of restricted, human-made stream systems (water trench or trench), *Parthenium hysterophorus* weed becomes plentifully because of the great accessibility of dampness and its seeds being conveyed by water system water channel.

High reproductive potential: *Parthenium hysterophorus* produce a gigantic amount of seeds with up to 15-25,000 seeds for every plant with an enormous seed bank, assessed around 2,00,000 seeds m^{-2} in uncovered grounds and horticulture field. Seeds of Parthenium can make due under cruel circumstances and stay practical for quite a while period. These characteristics of this weed help in its quick spreading.

Fast growth rate: It is enthusiastically developing yearly herbaceous weed. By and large, Parthenium blossomed when it is just four-multi week old and can bloom for quite a long time. Under horrible circumstances like salt and dry season pressure, the weed can finish its life cycle inside 4-5 weeks.

Impact of Parthenium

Impact on biodiversity: This weed can possibly upset the regular biological system, as it can develop all through the year in practically all exceptional circumstances stifling local vegetation. Quick spread of Parthenium can upset regular environment since it has extremely quick pervasion limit and allopathic potential which can disturb any sort of normal biological system. Species extravagance, equity a neighbourhood biodiversity step by step decline

where this plant is available, this present circumstance obviously demonstrates the local biodiversity loss of weeds and other yield plants because of Parthenium pervasion. Its pervasion is combined with its allopathic potential and the shortfall of its normal inhibitors like microbe, bugs and their hatchlings, these are some significant variable which are the explanation of its rich development and spread. The centralizations of allelochemicals viz. Coronopilin, caffeic corrosive, parthenin, and p-coumaric corrosive which are available in Parthenium have serious allelopathic impacts.

Impact on crop production: The *Parthenium hysterophorus* weed has plagued in a huge area of India. This plant contains parthenin, hysterin, hymenin, and ambrosin. Due to the presence of these allelochemicals this weed affects various harvests and person likewise. This toxic weed smother the advancement of adjacent plants by allelopathy. Leachate and concentrate of leaves and inflorescence forestall the germination and development of related financially significant harvests. Parthenium has solid allelopathic consequences for different plants even it can cause 40-80% yield misfortune in horticultural and agrarian harvests.

Impact on soil microflora: Parthenium is known to its inhibitory effect on growth and activity potential of different bacterial species related to Nitrogen assimilation such as Rhizobium, Azotobacter and nitrifying bacteria like Nitrosomonas.

Effects on animals: Parthenium weed is noxious for livestock, it can cause dermatitis and skin disorders in animals. Loss of skin pigmentation, dermatitis, mouth ulcers with extreme salivation and diarrhoea has been observed in animals. If excess amount of this weed is eaten by the animals, it can cause death.

Effects on human beings: Parthenium plant parts can be toxic to some people it is estimated up to 73% of people living with the weed are sensitive to it. Females are twice more likely to be sensitive than males. Dermatitis, hay fever, asthma, and bronchitis are the major health problems found in human beings caused by the pollen grains and other plant parts of Parthenium. The major allergens found in this plant are parthenin, coronopilin, tetraneuris and ambrosin. Its pollen grains are well known to causing asthma in human beings. Direct contact of this plant can cause dermatitis not only site specific but can spread all over the body.

Economic Importance of Parthenium: Parthenium is spreading at an alarming rate all over India and can adopt any climate very easily. In West Indies, this weed is used as a remedy against ulcerated sores, certain skin disease, facial neuralgia, fever and anaemia. Inflammation, eczema, skin rashes, herpes, rheumatic pain, cold heart trouble, menstrual disorders, difficulty during labour, stomach ache, diarrhoea, neurologic disorders, urinary infections, dysentery, malaria and insect bites are also treated. A preparation with ginger is effective for treating migraines during the early pain phase. It is also used as an additive with cattle manure in biogas production.

Health Benefits of Parthenium: Parthenium hyster-

ophorus has been found to be pharmacologically active as analgesic in muscular rheumatism. This weed is also reported as promising remedy against hepatic amoebiasis. Parthenin, the major constituent of the plant, exhibits significant medicinal attributes including anti-cancer properties. Flower extract of this weed can be used for developing drug for diabetes mellitus.

Developed public awareness and participatory approach to control weeds:

- ✓ Developing a participative approach for the control and management of Parthenium.
- ✓ Promoting new Parthenium research gathered via appropriate innovative and existing extension networks.
- ✓ Establishing Parthenium Action Groups both at Federal and Regional level, the aims of which are to eradicate or contain the weed.
- ✓ Developing and testing an appropriate participatory methodology for Parthenium management.
- ✓ Identifying effective information dissemination techniques to build awareness.
- ✓ Identifying novel approaches required to develop action by stakeholders with Parthenium in urban and rural areas.
- ✓ Studying the potential use of Parthenium. Information is available that it can be used for many purposes: Greenleaf manure, compost, bio pesticide and soil amendment.

Conclusion

The noxious *Parthenium hysterophorus* grows in a wide variety of habitats and cause changes in above ground vegetation as well as in below ground soil nutrients. It is capable of outcompeting native and non-native palatable plants that are important to livestock. The presence of several important chemical constituents mainly histamine, saponin, glucosides and triterpene (sesquiterpene) in the weed plant *P. hysterophorus* and their prominent biological activities in animal and human models indicate that the weed can be of use as it inherits various insecticidal, antifeedant, nematicidal, herbicidal antifungal, antimalarial, antibacterial and antiviral properties. The problem of wide spreading of Parthenium constitutes a major constraint to biodiversity, agriculture as well as human health. Mechanical, chemical and biological control strategies have been proved futile individually to curb proliferation of *P. hysterophorus*. So, integrated approaches are suggested to restrict the invasion of this weed.

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Role of Phytochelator in Heavy Metal Contaminated Soil

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Abstract

Soil contamination with heavy metals poses a significant threat to both environmental and human health, necessitating the development of sustainable and eco-friendly remediation strategies. Phytochelators cysteine-rich peptides and plant-derived chelating agents play a crucial role in the detoxification and stabilization of heavy metals through the formation of stable metal-chelate complexes. Key phytochelators, including phytochelatins, metallothioneins, organic acids, and certain amino acids, enhance metal uptake, compartmentalization, and tolerance in plants, thereby supporting various phytoremediation approaches, such as phytoextraction and phytostabilization. This report examines the biosynthesis, mechanisms of action, and environmental applications of phytochelators in the remediation of contaminated soils. It also highlights recent research, limitations, and future perspectives in optimizing phytochelator use for effective soil detoxification.

Introduction

Soil is essential for our food, forests, and clean water. Heavy metals (HMs), which have a density above 5 g cm^{-3}, pose significant environmental risks due to factors like agriculture, industrial growth, and population increase. These metals do not decompose and accumulate in the environment from sources such as fertilizers, sewage sludge, urban traffic, and mining. Their presence in agricultural lands can threaten public health by entering food chains, especially with the ongoing use of pesticides and chemical fertilizers.

Phytoremediation: Phytoremediation is an eco-friendly and cost-effective method for cleaning up contaminated sites. It maintains soil structure, boosts biodiversity, and often restores sites completely instead of just relocating pollution. There are several strategies, including:

Phytoextraction: Plants absorb metals from the soil and store them in their shoots for safe disposal.

Phytostabilization: Plants decrease the mobility of metals in the soil, preventing leaching into groundwater.

Phytovolatilization: Plants absorb metals and release them into the atmosphere as less harmful forms.

Rhizofiltration: Plant roots remove metals from contaminated water.

Phytoextraction is particularly important for discussing phytochelators, as it focuses on plants'

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abilities to concentrate metals.

Phytochelators: Phytochelators are crucial for plants to remediate heavy metal-contaminated soils. These small molecules and proteins, such as phytochelatins and metallothioneins, are produced in response to toxic metals like cadmium, lead, and mercury. They bind to heavy metal ions, reducing their harm and allowing for normal plant growth.

Types of Phytochelators

Phytochelators are specialized plant-produced molecules that bind and detoxify heavy metals. The two main categories in plants are phytochelatins (PCs) and metallothioneins (MTs), each with various subtypes and structural variants.

Phytochelatins (PCs): Phytochelatins (PCs) are metal-binding peptides with the universal structure (γ-Glu Cys) n-Gly (where n = 2-11), produced by plants in response to heavy metals like Hg, Cd, Ag, Ni, Cu, Pb, Au, Zn, and As (Gill and Tuteja, 2010). They play a crucial role in heavy metal management and detoxification, particularly in Cd tolerance (Yadav, 2010).

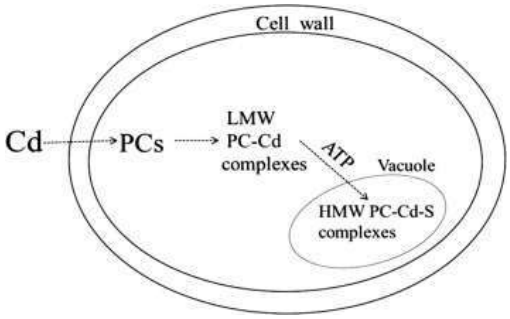

Fig. 1: Mechanisms of phytochelatins' decontamination of Cadmium heavy metal (Liu *et al*., 2015)

Phytochelatins are small, cysteine-rich peptides synthesized in the cytosol, with the general formula (γ-Glu-Cys)n(γ-Glu-Cys)n-Amino acid, where n ranges from 2 to 11. They bind cadmium (Cd), and the Cd-PC complex is transported across the tonoplasts by an ATP-binding transporter. The C-terminal amino acid is usually glycine (Gly) but can also be serine (Ser), glutamic acid (Glu), glutamine (Gln), alanine (Ala), β-alanine (βAla), asparagine (Asn), or cysteine (Cys), leading to iso-phytochelatins (iso-PCs). Variants include homo-phytochelatins (hPCs) with β-alanine in legumes, hydroxymethylphytochelatins (hydroxymethylPCs) with serine in cereals, and des-Gly PCs that lack glycine.

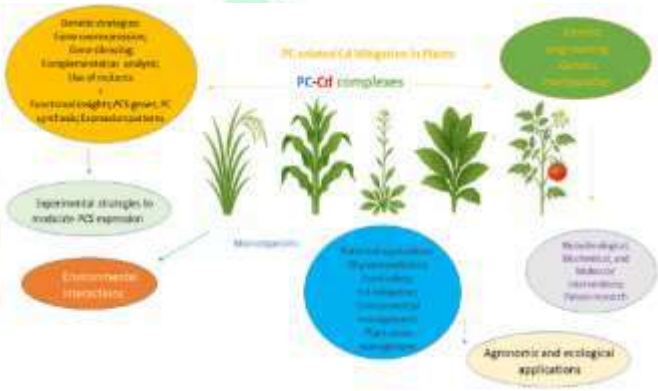

Fig. 2: Overview of PC-related Cd mitigation research in plants employing genetic manipulation strategies (Marques *et al.*, 2025)

Metallothioneins (MTs): Metallothioneins are small, cysteine-rich proteins that bind metals via thiol groups, and they are classified into four subfamilies in plants: p1 (Class 1), p2 (Class 2), p3 (Class 3), and pec (Class 4); these proteins are encoded by a multi-gene family, with different types found in various species such as Arabidopsis, rice, and sugarcane.

Other Metal Chelators: Although not always classified as "phytochelators," plants also use:

Low Molecular Weight Organic Acids (LMWO

As): Compounds like citric and malic acids that chelate metals in the rhizosphere.

Amino acids, Such as histidine, have specific roles in chelating and transporting metals (especially nickel).

Siderophores: More commonly from microbes, but some plants also secrete iron-binding ligands.

Biosynthetic pathway of phytochelatin

Pathway Steps

Glutathione Synthesis

- ✓ Glutathione is synthesized from three amino acids: glutamate, cysteine, and glycine.
- ✓ This occurs in two steps, catalyzed by γ-glutamylcysteine synthetase and glutathione synthetase**.**

Phytochelatin Synthesis (Key Step)

- ✓ Phytochelatin synthase transfers a γ-glutamylcysteine moiety from one molecule of glutathione onto another glutathione (or onto an existing phytochelatin), forming phytochelatins with the general structure: $(\gamma\text{-Glu-Cys})_n\text{-Gly}$, where n = 2-11.
- ✓ The enzyme action is metal-activated: heavy metals bind to glutathione, which then stimulates PCS activity.

Phytochelatin Elongation: PCS can add further γ-Glu-Cys units to the peptide chain, lengthening the phytochelatin molecule.

Metal Chelation: Newly formed phytochelatins rapidly bind and detoxify incoming metal ions by forming stable complexes, which are transported into the vacuole for sequestration.

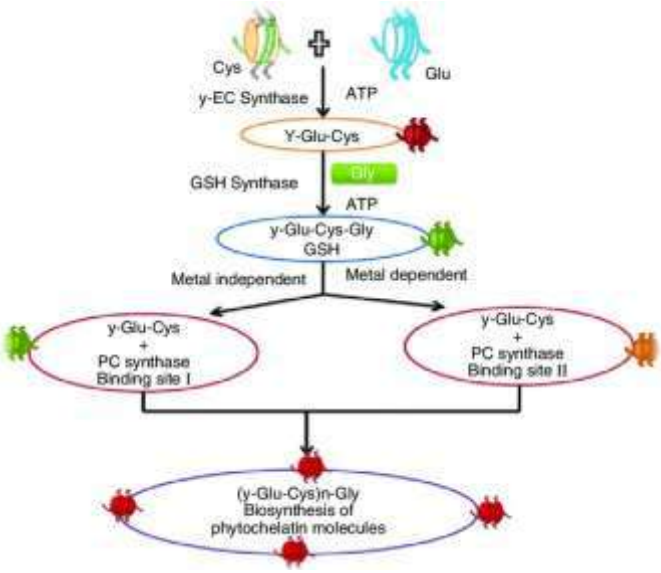

Fig. 3: Biosynthetic pathway of phytochelatin (Chaudhary *et al.*, 2018)

Mechanisms of Phytochelators in Soil Remediation: Phytochelators, particularly phytochelatins and metallothioneins, play key roles in the remediation of heavy metal-contaminated soils by enabling plants to detoxify, sequester and sometimes extract these toxic elements. Their action forms the molecular basis for several phytoremediation mechanisms, especially phytoextraction and phytostabilization.

Key Mechanisms

Heavy Metal Chelation and Detoxification: Phytochelatins are small peptides produced in plants exposed to heavy metals such as cadmium (Cd), arsenic (As), lead (Pb), and mercury (Hg). They bind to these metals through thiol groups, forming stable complexes that reduce toxic metal ion concentrations in the plant's cytosol, detoxifying them and preventing interaction with vital cellular components.

Sequestration and Compartmentalization: The

metal-phytochelatin complexes are transported into vacuoles, sequestering the metals away from sensitive metabolic processes and limiting their toxicity. This mechanism also reduces metal redistribution within the plant.

Facilitating Uptake and Translocation (Phyto-extraction): Phytochelators enhance a plant's ability to absorb and transport heavy metals from the soil to above-ground tissues, enabling plants to extract contaminants effectively. Genetic modifications to overexpress phytochelatin synthase also boost resistance to heavy metal toxicity.

Stabilizing Metals in the Root Zone (Phyto-stabilization): Phytochelators can immobilize heavy metals in roots or the surrounding soil, reducing their mobility and bioavailability, which helps prevent leaching into groundwater.

Interplay with Rhizosphere Microorganisms: Interactions between plants and rhizosphere microorganisms promote phytochelator production and enhance metal availability, as beneficial microbes can secrete additional chelators or produce enzymes that support metal uptake and plant health.

Table 1: Phytochelator Mechanisms in Soil Remediation

Mechanism	Action	Outcome
Chelation/ detoxification	Phytochelatins bind metal ions	Reduces toxicity
Compart-mentalization	Transport of comp-lexes into vacuoles	Safely sequesters metals
Phytoextraction facilitation	Enhanced uptake and accumulation in shoots	Allows pollutant removal
Phyto-stabilization	Immobilization in roots/rhizosphere	Limits metal mobility
Synergy with microbes	Promotes metal solu-bility and plant tolerance via rhizo-biome	Increases remediation from soils

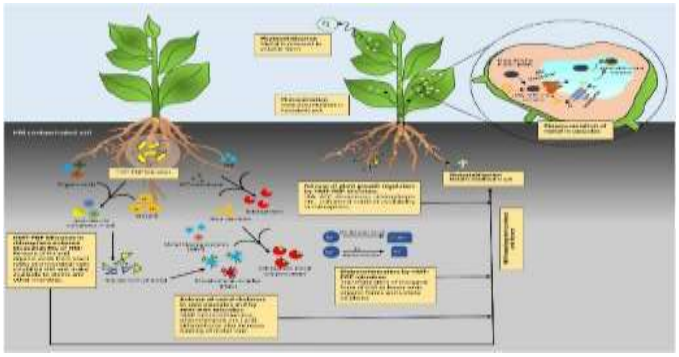

Figure 4. Overview of phytotochelation in phyto-remediation (Mishra *et al*., 2017)

Plant producing phytochelatin

Table 2: Plant producing phytochelator Compound

Plant Species	Phytochelator Compound	Reference
Arabidopsis thaliana	PC2-Gly, PC3-Gly, PC4-Gly, PC5-Gly	Clemens, 2014
Zea mays (Maize)	PC2-Gly, PC3-Glu, des-Gly PCs	Hu *et al*., 2023
Oryza sativa (Rice)	PC2-Gly, PC3-Gln, PC4-Cys, des-Gly PCs	Hu *et al*., 2023
Triticum aestivum (Wheat)	Phytochelatins,PC2–PC4	Hu *et al*., 2023
Glycine max (Soybean)	hPCs (with β-Ala), PC2–PC4	Hu *et al*., 2023

Phytochelators Importance

Phytochelators, mainly phytochelatins and glutathione, are essential molecules produced by plants that help them survive in heavy metal-polluted environments.

Natural Detoxifiers: Phytochelators bind toxic metal ions, converting them into stable, non-toxic complexes, thus protecting vital plant processes like photosynthesis. For instance, cadmium (Cd^{2+}) becomes inactive when bound by phytochelatin.

Phytoremediation: These molecules are crucial for phytoremediation, a green technique utilizing plants to clean pollution. Benefits include being cost-effective, eco-friendly, and applicable to large areas.

Crop Protection: In contaminated agriculture,

Crops Using Phytochelators for Heavy Metal Detoxification

Table 3: Crops Using Phytochelators for Heavy Metal Detoxification and Their Role (Shukla *et al.*, 2013)

Plant Species	Heavy Metals Tolerated	Phytochelator Compound	Role/Mechanism
Brassica juncea (Indian mustard)	Pb, Cd, Zn, Cr, Ni	Phytochelatin 2-4 (PC2-PC4)	Chelates Cd and Pb; stores in vacuoles to reduce toxicity
Helianthus annuus (Sunflower)	Cd, Pb, U, As	Phytochelatin 2 (PC2)	Detoxification via vacuolar sequestration: role in uranium and arsenic clean-up
Oryza sativa (Rice)	As, Cd, Hg	Glutathione, Phytochelatin 3 (PC3)	Chelates arsenic and cadmium; restricts translocation to edible grains
Brassica rapa (Chinese cabbage)	Cd, Ni	Phytochelatin 2-3 (PC2, PC3)	Limits Cd mobility and accumulation in shoots
Hordeum vulgare (Barley)	Zn, Pb, Cu	Glutathione (GSH), PC2–PC4	High antioxidant and phytochelatin response; Zn-Cu chelation in roots
Pteris vittata (Brake Fern)	As	Phytochelatin 2, arsenic-PC complex	Stores arsenic in fronds using PC complexes; excellent arsenic hyperaccumulator
Zea mays (Maize/Corn)	Cd, Pb, Zn	PC2, PC3, GSH	PCs sequester Cd and Pb in roots; reduced metal translocation to leaves
Triticum aestivum (Wheat)	Cd, Cu, Zn, Pb	Phytochelatin 2, 3 (PC2, PC3)	Reduces heavy metal accumulation in grains; used in safe cropping practices
Spinacia oleracea (Spinach)	Cd, Cu, Zn	PC2, PC3, GSH	Effective in metal uptake and detoxification; chelates Cd in leaf tissues
Phaseolus vulgaris (Common bean)	Cd, Pb	PC2, PC4, GSH	Reduces oxidative stress and chelates metals in roots and leaves
Glycine max (Soybean)	Cd, Pb, Zn	Phytochelatin 2-4, GSH	Enhances antioxidant defense; binds Cd and Zn effectively
Amaranthus spp. (Amaranth)	Cd, Pb	Phytochelatin-like peptides (PCn)	Strong metal accumulation; active chelation and detoxification of Cd and Pb
Cajanus cajan (Pigeon Pea)	Zn, Pb	PC2, GSH	Moderate accumulator; helps in Zn detox and Pb immobilization
Vigna radiate (Green Gram)	Pb, Cd	PC2, PC3, GSH	Prevents Pb/Cd transfer to shoots; maintains redox balance

phytochelators limit toxic metal absorption in edible parts, allowing safe cultivation and reducing bioaccumulation risks in the food chain.

Defense against Oxidative Stress: Phytochelators also act as antioxidants that protect against reactive oxygen species (ROS), fulfilling dual roles in chelating metals and neutralizing oxidative damage.

Genetic Improvement: Research is focused on enhancing phytochelatin synthase genes and glutathione pathways to create resilient, metal-tolerant transgenic crops.

Environmental and Social Impact: Using phyto-chelator-efficient plants can restore degraded lands and aid local farming in polluted regions, promoting environmental justice through low-cost cleanup solutions.

Conclusion

Phytochelatins are peptides derived from glutathione, produced by most plant species in response to heavy metal exposure. They play a vital role in detoxifying metals like cadmium, arsenic, lead, and zinc. These compounds differ in structure, particularly in chain length and C-terminal amino acids, resulting in various phytochelatin types among plants.Classical phytochelatins, typically featuring glycine at the C-terminus, are common, while some

grasses and legumes produce iso-phytochelatins with residues like β-alanine or serine. Legumes often have homo-phytochelatins with β-alanine, and des-Gly phytochelatins are found in maize.Phytochelatin types and concentrations vary among species, tissues, metal loads, and environmental conditions, allowing plants to adapt to metal stresses and improving their detoxification and phytoremediation capabilities. This diversity is crucial for heavy metal tolerance in the plant kingdom.

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Role of Artificial Intelligence in Policy Making

M. Poojith Kumar Reddy and B. Sridhar Naik

Abstract

Artificial Intelligence (AI) is reshaping the policymaking process by enabling faster data analysis, predictive modeling, and more targeted public services. From issue detection to policy evaluation, AI enhances efficiency, transparency and responsiveness in governance. Real-world applications in countries like India, Singapore and the United States demonstrate its transformative impact. However, ethical concerns such as algorithmic bias, lack of transparency and accountability gaps must be addressed. Responsible AI integration rooted in fairness, oversight, and privacy is essential for equitable and democratic governance.

Introduction

Artificial Intelligence (AI) has become an increasingly important tool in policymaking due to its ability to analyse vast amounts of data quickly and accurately. The integration of AI into policy-making processes has the potential to revolutionise how decisions are made, leading to more efficient and effective governance. Traditionally, policymaking has been a time-intensive and data-constrained process, often reactive and limited by human analytical capacity. However, with the rise of AI technologies such as machine learning, natural language processing, and predictive analytics governments now have tools that can process vast datasets in real time, uncover hidden patterns, simulate complex scenarios and generate evidence-based recommendations.

The integration of AI into policymaking processes holds the potential to make governance more proactive, efficient, transparent, and inclusive. AI can support every stage of the policy cycle from early detection of emerging challenges, such as disease outbreaks or economic shifts, to crafting and evaluating policy interventions that are better tailored to real-world dynamics. For example, AI-enabled surveillance systems in public health, smart allocation of city resources, and predictive modeling for climate adaptation are already demonstrating tangible benefits. Nonetheless, the growing use of AI in governance also raises critical concerns regarding ethical use, data privacy, algorithmic bias and the risk of replacing human judgment with opaque machine decisions. Policymakers must balance the advantages of automation and intelligence with the

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need for democratic accountability, fairness and public trust.

Stages of AI in Policy Making

Identification and Issue Detection: AI rapidly processes large datasets (e.g., health, economics, social media) to detect patterns and emerging issues.

Example: In Australia, the Victoria State Government uses "syndromic surveillance" to track anomalies in health data, enabling real-time detection of public health concerns.

Policy Formulation: AI forecasting and simulation tools model policy impacts, helping optimise policy design.

Example: Quebec uses AI to analyse labour and economic data, tailoring local development plans and guiding targeted investment.

Policy Adoption and Decision Making: AI supports lawmakers with tools for agenda planning and impact simulation.

Example: AI can help legislative bodies rank bills by priority, predict resistance, or plan resource allocation.

Policy Implementation: AI helps allocate resources, automate services, and target interventions.

Example: New Orleans used AI to optimize ambulance placement across the city, cutting response times by focusing on underserved locations.

Policy Evaluation and Monitoring: AI compares post-implementation data to predictions, identifying gaps or unintended effects.

Example: India's Aarogya Setu app tracked COVID-19 spread and helped evaluate the effectiveness of lockdowns, while raising valid concerns around data privacy.

Key Benefits of AI in Policy Making

Data Processing Power: Rapid analysis of large and complex datasets to support evidence-based policymaking.

Pattern Recognition: Early detection of risks or systemic issues.

Forecasting Capability: Anticipate outcomes before implementation.

Efficiency Gains: Reduce administrative workloads through automation.

Targeted Services: Personalise government programs based on data.

Improved Accuracy and Consistency: Eliminate human error and bias in analysis.

Transparency and Accountability: Enhance public trust by documenting algorithmic processes.

Disadvantages of AI in Policy Making

Lack of Transparency: Complex algorithms make it difficult to understand or explain how decisions are made.

Risk of Bias: AI can reflect and perpetuate existing inequalities if not carefully designed.

Unintended Consequences: Algorithms may optimise goals without considering broader societal impacts.

Loss of Human Judgment: Absence of empathy, ethical reasoning, and creativity in AI-driven decisions.

Accountability Gaps: Challenges in attributing responsibility for AI-generated decisions.

Ethical Considerations and Responsible AI Use

AI in policy must reflect core public values: fairness, accountability, and transparency.

- ✓ There must be human oversight to ensure ethical decision-making.
- ✓ Privacy, bias mitigation, and informed consent must be prioritized to maintain public trust.
- ✓ Clear standards and regulatory frameworks are needed for ethical AI use in government.

Summary of Impactful Examples

Singapore: Chatbots (Jamie) has revolutionized the citizen engagement.

New Orleans: AI-optimised ambulance placement improving emergency response.

India: AI-enabled pandemic contact tracing and real-time policy adjustments.

United Nations: AI-assisted economic forecasting for climate investment planning.

Conclusion

Artificial Intelligence is transforming the policymaking landscape by improving how problems are detected, how solutions are crafted, and how outcomes are evaluated. However, it must be adopted responsibly, anchored in ethical principles, human judgment, and democratic oversight. When harnessed correctly, AI has the potential to empower governments to serve society more effectively and equitably. To realize this potential, governments must invest in AI literacy, build transparent data governance frameworks and promote interdisciplinary collaboration between technologists, policymakers, and civil society.

Continuous monitoring and evaluation of AI systems are essential to minimize unintended consequences and ensure inclusive benefits. As the role of AI in governance expands, proactive and ethical policy-making will determine its long-term legitimacy and public trust.

Shifting Patterns in Consumer Behaviour in Rural and Urban Areas

Swetha Kodali and Ch. Tejaswi

Abstract

This article on transforming trends in rural and urban consumer behaviour examines the changing dynamics of consumerism, emphasizing a notable shift from conventional urban-rural classifications. It suggests that, urban consumers are shifting their focus from physical goods towards valuing experiences, sustainability, and personal ethics, motivated by a "conscious consumption" mentality and a desire for convenience. At the same time, rural consumers are experiencing a "digital empowerment," with increased income and enhanced connectivity fostering a strong desire for branded, premium products. The article claims that these developments are blurring the distinctions between the two markets, leading to a future where a generalized strategy is no longer suitable. It concludes that businesses need to implement targeted marketing efforts, hybrid distribution models, and innovation anchored in value to effectively navigate this interconnected marketplace and respond to the evolving needs of a new wave of consumers.

Introduction

The world is a marketplace, and in this bustling ground, a fascinating divergence is taking shape. For years, we've thought of consumer behaviour in two distinct silos: the fast-paced, trend-driven urban consumer and the value-conscious, tradition-bound rural one. However, the lines are blurring, and a new, more nuanced picture of consumerism is emerging. Technology, rising incomes, and changing aspirations are rewriting the rules of the game for both urban and rural buyers.

The Urban Consumer: Beyond "Just Stuff": Urban consumerism has historically been characterized by a craving for freshness, convenience, and luxury. However, this has changed in recent years. The modern urban consumer is now focused not only on acquiring goods but also on investing in experiences, ethical values, and a particular way of life.

The rise of conscious consumption: As awareness of environmental and social issues grows, urban consumers are placing greater importance on brands that demonstrate sustainability, ethical sourcing, and transparency. They are prepared to spend more on organic fruits and vegetables, eco-conscious packaging, and items from businesses that reflect their personal values. This marks a notable change from the previous trend of "label-driven" consumption,

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where brand names primarily signified status.

The search for ease and customization: Life in the city often feels like a relentless rush. This urgency has created a desire for services that deliver products directly, transforming e-commerce and on-demand deliveries into essential aspects of life rather than mere luxuries. Urban shoppers now anticipate seamless and personalized experiences, whether it's for grocery delivery, meal kits, or rapid commerce. To appeal to this demographic, brands must adopt AI-powered suggestions and customized marketing strategies as fundamental requirements.

Experiences are prioritized over possessions: The temptation to have the newest device or high-end fashion item is being countered by a longing for distinctive experiences. City dwellers are investing more in travel, dining, and entertainment. This movement indicates a transition from gathering physical items to cherishing memories and narratives.

The Rural Revolution: A New Aspiration

The story surrounding rural consumers is experiencing a significant transformation. Traditionally, this demographic was perceived as sensitive to pricing and reluctant to embrace new trends. Yet, this perception has shifted. A multitude of factors is driving a fresh surge of consumerism in rural areas.

Digital empowerment: The rise of smartphones and the availability of low-cost data plans have transformed the landscape. With countless rural users accessing the internet, digital connectivity has eliminated the information gap that used to exist. Now, rural consumers can find online reviews, compare prices, and explore a wide range of products that were previously out of reach. Social media platforms, in essence, are crucial in influencing brand recognition and purchasing choices.

The preference for branded quality: The era of selecting unbranded or less expensive local merchandise is diminishing. Increased income levels and exposure to urban lifestyles have fuelled a rising desire for quality and brand-name products. This trend is evident across various sectorsincluding fast-moving consumer goods, electronics, and even vehicles, as rural consumers are choosing to "upgrade" their purchases, showcasing a notable rise in purchasing power. For example, some reports suggest that rural buyers are transitioning from cheaper cars to pricier SUVs, a shift that was previously limited to urban markets.

A new type of brand loyalty: Urban consumers tend to be more open to trying out digital-first brands, whereas rural consumers exhibit a stronger attachment to well-established, trusted names. Legacy FMCG companies with extensive distribution networks are effectively utilizing their brand reputation to gain a larger portion of the rural market. Nonetheless, this loyalty is not unconditional. It is a loyalty rooted in trust and confidence in quality, often stemming from targeted marketing that directly addresses their needs.

The Blurring Lines: What's Next?

The changing patterns of consumer behaviour in both rural and urban areas suggest a future

where these markets, although still separate, are becoming more interconnected. Rural consumers are increasingly adopting "urban" aspirations, while urban consumers are seeking more "rural" experiences that emphasize authenticity and alignment with their values. This shift indicates that businesses can no longer rely on a universal approach. Companies need to create tailored strategies that address the distinct traits of each market. This involves:

Precision marketing: Leveraging data insights to develop tailored and pertinent campaigns for audiences in both urban and rural settings.

Blended distribution strategies: Merging the benefits of e-commerce with a solid physical presence and efficient distribution systems to guarantee product accessibility, even in the most isolated regions.

Innovation focused on value: Emphasizing products that not only provide quality and convenience but also resonate with the social and environmental values of a new generation of consumers, irrespective of their location.

The evolving landscape of consumerism reflects the ever-shifting characteristics of our society. It narrates a tale of empowerment, ambition, and a world that feels increasingly interconnected. Grasping these trends goes beyond merely increasing sales; it involves comprehending individuals, their aspirations, and their desires, one transaction at a time.

The Major Transformation: How Rural and Urban Shoppers Are Redefining Marketplace Dynamics

There was a period when we could easily categorize consumers into two distinct groups. Urban shoppers chased after the latest trends, while rural consumers preferred familiar and budget-friendly choices. However, that straightforward narrative has become outdated. A more profound and emotional shift is currently taking place, influenced by aspiration, consciousness, and the power of connection.

Urban Changes: Purchasing with Purpose: In urban areas, consumer behaviour transcends mere acquisition. It's centred on significance. Whether it's ethically sourced coffee or eco-friendly packaging, individuals want their purchases to embody their principles. Moreover, they expect it immediately delivered via seamless apps, customized deals and rapid deliveries.

Purpose-driven buying decisions: Consumers are inquiring, "Is this brand committed to environmental sustainability?"

- ✓ **Time valued as currency:** If a service provides time savings, it fosters customer loyalty.
- ✓ **Experiences prioritized over possession:** Weekend trips, fine dining, and memorable stories outweigh the appeal of additional luxury items. It's not just a trend it's a shift in identity.

Rural Renaissance: Aspirations on the Rise

Beyond the city lights, an incredible trans-formation is underway. With the help of smartphones and affordable data, rural areas are gaining a fresh

sense of assurance and options. This is more than mere access; it's a form of empowerment.

- ✓ **Information revolution:** Evaluations, contrasts, and trending content are now accessible in distant villages.
- ✓ **The emergence of the branded rural consumer:** SUVs, stylish electronics, and reliable FMCG products are increasingly entering rural households.
- ✓ **Established loyalty:** Rural consumers remain loyal to brands that are present, establish trust, and communicate in their native language.

A Future of Blended Dreams

The distinctions between urban and rural markets are becoming less pronounced. Urban consumers seek authenticity and values, while rural consumers prioritize quality and aspiration. The boundaries are merging, and in this common territory, brands must communicate with sensitivity.

Here's what companies need to adopt

- ✓ Highly specific marketing that feels tailored not impersonal
- ✓ Combined models that cater to both the digitally savvy and those who prefer in-person experiences.
- ✓ Products with purpose solutions that address genuine needs and embody true values

Conclusion

This concludes that the evolution of consumerism in both urban and rural areas reflects a broader societal transformation. The old-style split between the two is collapsing, giving way to a more interconnected marketplace driven by shared aspirations for quality, purpose, and convenience. Businesses that recognize this shift and adapt their strategies will be best positioned for success. This requires moving beyond a one-size-fits-all approach and creating targeted, value-driven campaigns that resonate with the unique desires of each consumer, regardless of their location. The future of commerce isn't about two separate worlds, but rather a unified landscape where empowerment, ambition, and authentic connection are the driving forces behind every purchase.

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Drones in Agriculture: Transforming Farming from the Sky

Nutan Yadav D. and Harshith Gowda T. P.

Abstract

Drones are becoming one of agriculture's most useful innovations, allowing farmers to scout crops, deliver inputs exactly where they are needed, and base decisions on data. From detecting pests early to optimizing irrigation timing, drone tech is making operations more efficient, cutting costs, and saving on environmental degradation. Japan, India, and the United States have already implemented agricultural drones at scale, showing that they can revolutionize conventional farming. However, technical training requirements, cost, and regulatory impediments need to be overcome for mass adoption. Sustainable agricultural growth will result from responsible incorporation of drone technology through farmer education and transparent policies.

Introduction

Farming has ever been influenced by technology, but the advent of drones heralds a revolutionary change in the way farming businesses are run. Unmanned Aerial Vehicles or simply drones are capable of being fitted with high-tech sensors, cameras, and GPS that allow farmers to view their farms from above and receive information that was before very time-consuming or unattainable. In most parts of the world, agriculture is under immense pressure from labour scarcity, uncertain climatic conditions, and having to grow more food in a sustainable manner. Drones provide a convenient and innovative answer by making precision farming possible, where every choice is made from real-time information. Not only does this enhance returns, but also saves wastage of resources such as water, fertilizers, and pesticides. By incorporating drones into standard farming operations, farmers can shift from reactive to proactive decision-making, allowing for improved productivity and environmental responsibility.

Applications of Drones in Agriculture

Crop Health Monitoring: Drones with multispectral and hyperspectral sensors can pick up on early indicators of plant stress, pest attacks, or nutrient imbalance. These sensors are able to detect light outside the human visual spectrum, showing plant health metrics undetectable to humans. In Punjab, India, farmers have effectively utilized drones to detect fungal diseases in paddy plants days ahead of time when they became visible, enabling early intervention.

Precision Spraying: Precision herbicide, pesticide, and fertilizer spraying is one of the most significant applications for drones. By focusing primarily on the

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affected areas, drones lower input costs and lessen environmental harm. In Japan, autonomous drones regularly spray rice fields, completing tasks that would take labourers hours to complete in a matter of minutes.

Irrigation Management: Thermal imaging cameras installed on drones are able to spot under-watered and over-watered sections of a field. This information allows farmers to realign irrigation systems and schedules effectively. For instance, vineyards in California employ drones to monitor grapevine water stress, minimizing water consumption during extended droughts.

Field Mapping and Planning: With GPS and high-definition cameras, drones can produce precise topographic maps of agricultural land. Drones assist with planning planting design, drainage systems, and soil management plans, which result in more efficient farm design.

Yield Estimation: Drones can measure plant density, height, and health to estimate yields prior to harvesting. This enables farmers to better plan for storage, marketing, and distribution.

Benefits of Drones in Agriculture

Time Efficiency: Cover large areas in minutes rather than days.

Cost Savings: Save labour costs and maximize application of fertilizers and pesticides.

Environmental Protection: Avoid excessive use of chemicals and runoff into waterways.

Better Decision Making: Get reliable, real-time information for better decisions.

Accessibility: Function in challenging landscapes where conventional equipment cannot reach.

Challenges and Limitations

High Upfront Cost: Sophisticated drones with sensors may be too costly for low-scale farmers.

Regulatory Barriers: Most nations have stringent drone operation policies that restrict agricultural applications.

Technical Skills: Farmers require training to fly drones and understand data gathered.

Weather Dependence: Adverse weather conditions such as rain, fog, and strong winds can disrupt drone operations.

Maintenance and Repairs: Regular expenses for maintenance and part replacement can be a hindrance.

Ethical and Policy Considerations

The application of drones in the agricultural sector raises important policy and ethical issues. Farmer privacy data should be safeguarded to avoid exploitation by corporations or third parties. Equitable access to technology should be guaranteed by policies so that smallholder farmers will not be left behind. Properly defined regulations on the flight routes of drones, safety requirements, and acceptable use are necessary for public confidence and smooth integration.

Global Examples of Drone Adoption

Japan: More than 40% of rice fields employ drone spraying for pesticides and fertilizers.

India: Subsidies by the government persuade small farmers to implement drones for crop monitoring and

spraying.

USA: Large farms utilize drones for mapping, irrigation management, and pest identification.

Conclusion

Agriculture is being transformed by drones with their unparalleled efficiency, precision, and sustainability advantages. With their capacity to gather and analyse real-time data, drones enable farmers to make better decisions, enhancing yields and resource saving. Nevertheless, in order to reach their full potential, investments should be directed towards farmer training, cost-cutting measures, and facilitating policy frameworks. As drone technology gets cheaper and more accessible, it could soon become as ubiquitous in farming as tractors used to be, ushering in an era of smart farming.

Diamond Back Moth: Biology, Damage and Integrated Pest Management Strategies in Crop Ecosystem

Sandeep V. and S. Padmavathi

Abstract

The diamondback moth is a damaging pest of *Brassica* crops that results in an estimated $4-5 billion in economic losses every year. With larvae that feed on foliage, stems, and reproductive organs, the pest develops quickly and completes several overlapping generations annually, causing the most harm. An integrated strategy incorporating cultural methods such as crop rotation, trap cropping, and the adoption of resistant cultivars is necessary for effective control. Selective chemical treatments were employed when infestations surpassed economic limits, while biological control using parasitoids was employed for long-term suppression. Populations are naturally decreased by environmental conditions like low temperatures and rainfall.

Introduction

As per the 2020 survey, the diamondback moth, *Plutella xylostella* (L.) (Lepidoptera: Plutellidae), is the most damaging insect pest of Brassica crops globally, causing an annual loss of $4-5 billion.

The host plants of DBM include: Only Brassicaceae (crucifers) such as broccoli, cauliflower, cabbage, kohlrabi, turnip, brussels sprouts, mustard seed, rapeseed, canola, wild mustard, radish and turnip, pepper weed, winter cress, kale, mustard, etc. are consumed by diamondback moth larvae.

Biology

Egg: The flattened, oval eggs are pale green or yellow at first, then turn dark. They are found on the upper and lower surfaces of leaves, usually in depressions, and infrequently on stems or petioles. They can be found alone or in small clusters of two or ten eggs. Despite the possibility of depositing 250-300 eggs, females typically produce 150 eggs overall. The typical development period is five to six days.

Larvae: Larvae, which have four instars and finish in 15-17 days, are the harmful stage. A characteristic "V" is formed by the protuberances that extend from the rear end of the larval body, which tapers at both ends. Larvae stay quite tiny and active throughout their growth process. Although they are so little that it is hard to see the mines, first instar larvae initially feed by mining leaves. After emerging from their mines at the end of the first instar, the larvae molt beneath the leaf and then feed on the leaf's underside. While the upper leaf epidermis is frequently left

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undamaged, their chewing causes sporadic areas of harm.

Pupae: Usually developed on the lower or outer leaves, the diamond back moth's (*Plutella xylostella*) pupae are enveloped in a white, loose, silken cocoon. They usually lurk in cracks close to the bud and adhere to leaves. Pupation may take place in the florets of broccoli and cauliflower. Overall, it lasted between five and fifteen days.

Adult: The adult moth is greyish-brown, tiny, and thin. It has a wide cream or light brown band along the length of it, which is approximately 6 mm. The most common diagnostic feature and common name for this insect is the diamond-shaped band that forms on the dorsal side. The tips of the wings appear to curve slightly upward when viewed from the side. Females lay eggs for roughly 10 days, whereas adult males and females survive for roughly 12 and 16 days, respectively. The moths are not very good flyers; they typically fly no more than two meters above the ground. Nevertheless, moths cannot withstand harsh winters and are easily carried by the wind. In one year, the moth can complete 6 to 7 life cycles. Generations overlap throughout the warmer months of the year.

Fig. 1 Biology and life cycle of diamond back moth

Damaging symptoms: DBM caterpillars consume the leaves, stems, flower heads, and pods of plants. Despite their tiny size, the larvae can be exceedingly numerous, causing all foliar tissue to be completely removed save for the veins in the leaves. The majority of the damage is brought on by the caterpillars munching on flower buds, blooms, and pods while tunneling into the crowns of plants like cabbage and Brussels sprouts. By pupating inside cauliflower curds and broccoli florets, they also contaminate produce. The white blotches are caused by immature larvae scraping the epidermal leaf tissues. The leaves appear withered, but later on, larvae pierce the leaves, drill into pods, and feed on the growing seed. The majority of severely damaged plants will die, and they may appear stunted. Extensive feeding on reproductive plant parts will significantly reduce yields.

Fig. 2: Damage symptoms of diamond back moth in cauliflower and cabbage crop in field

Management

- ✓ After the crop is harvested, clear the field of all trash and stubble.
- ✓ To attract DBM for oviposition, grow mustard as a trap crop at a 2:1 ratio (mustard: cabbage) at least ten days before the main crop is planted.
- ✓ Setting up pheromone traps in the field at a rate of 12 ha^{-1}
- ✓ Crop rotation using melon, tomatoes, beans, peas, and cucurbits as alternate hosts
- ✓ Rainfall frequently kills a significant percentage of young larvae, and adult moths cannot withstand cold temperatures (winter).

- ✓ The development of resistant cultivars, such as glossy types that are resistant to larvae, lack the typical waxy bloom, and are dark green instead of grayish green. Thus, it appears that larvae spend less time feeding on glossy variants and more time searching.
- ✓ Larval parasitoids: *Cotesia plutellae* at 20,000 ha^{-1} and *Diadegma semiclausm* at 1,00,000 ha^{-1}, released 20 days after planting. The parasitoids frequently kill the large larvae, prepupae, and pupae. Certain natural enemies of *Plutella xylostella* include *Diadegma insulare* (Ichneumonidae), *Microplitis plutellae* (Braconidae), and *Diadromus subtilicornis* (Ichneumonidae).
- ✓ When there are 20 larvae per 10 plants, take insecticide application into consideration.
- ✓ 2 g lit^{-1} of *Bacillus thuringiensis* var. *kurstaki*
- ✓ 1 milliliter $liter^{-1}$ of Cypermethrin.
- ✓ Extract from neem seed kernels 5%-5.0 ml/10 lit
- ✓ Concentrate of Azadirachtin 5% Neem Extract - 5.0 ml/10 lit
- ✓ 5.4% EC-1.2 ml lit^{-1} Lufenuron
- ✓ 2.5% SC-1.2 ml lit^{-1} of Spinosad
- ✓ 50 percent EC-1.0 ml lit^{-1} Trichlorfon 5% -37.5 kg ha^{-1} Malathion.

Conclusion

The diamondback moth is an extremely damaging pest that becomes resistant to the majority of pesticides. Integrated tactics, such as cultural methods including crop rotation, trap cropping, and resistant cultivars, are necessary for efficient management. When pest thresholds are surpassed, prudent chemical use works well, but biological management with parasitoids offers long-lasting suppression. Rainfall and chilly winters are examples of natural elements that contributed to population decline. By combining these strategies, damage is reduced, yields are increased, and sustainable agriculture is supported.

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Mycorrhiza for Sustainable Agro-ecology

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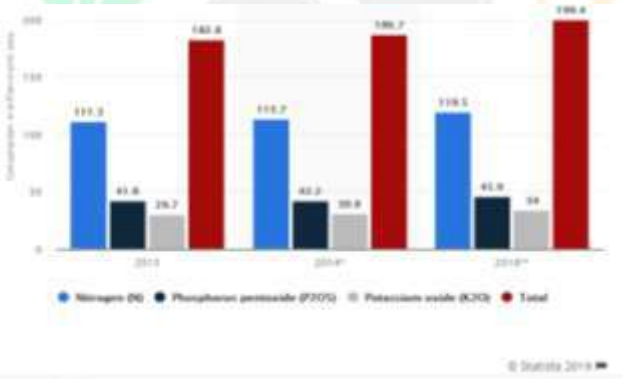
According to a recent report by a consortium of agriculture institutes, out of 350 million hectares of soil in India, 120 million hectares has already turned problematic, that is, either the soil has turned either acidic or alkaline. The carbon content in the soil is found to be decreasing while the salinity is increasing. Coupled with the excess spraying of fertilizers that affects the nutritional value of the soil, the report suggests that the country is on the verge of a soil crisis that can have a big impact on agriculture productivity, sustainability and also on human health.



Vibrant agriculture is dependent upon many a factors, among which proper and judicious soil nutrient management practices comes first. There are seventeen elements are known to be essential for plants. Among which nitrogen, phosphorous and potassium plays vital role and they are considered as major plant nutrients. Among horticultural crops, floriculture is growing at alarming rate both in open and protected cultivation. Proper growth and development of the plant is ultimately effected by regular nutritional management. Yields of various crops have reached a plateau or are on the decline. This is of serious consequence given increasing population and diminishing per capita land availability. Several methods of nutrient management have been practiced on farms, however, the best option for the farmer is an integration of organic and inorganic approaches to nutrient management. This far a lot of emphasis has been placed on the conservation and management of N-one of the earliest reported scarce plant nutrient. However, current studies across India have shown a gradual and alarming depletion of potassium and increase in P fixation leading to sustainability concerns for these two nutrients. Among other nutrients S, Zn and B are also reaching deficient status in Indian soils. This sustainability crisis needs to be addressed holistically. This paper explains the philosophy, strategies and practices available to various users of sustainable nutrient management. The paradigm of green revolution emphasized the impressive gains in the food production which on the other hand concern on the soil health and sustainability were given

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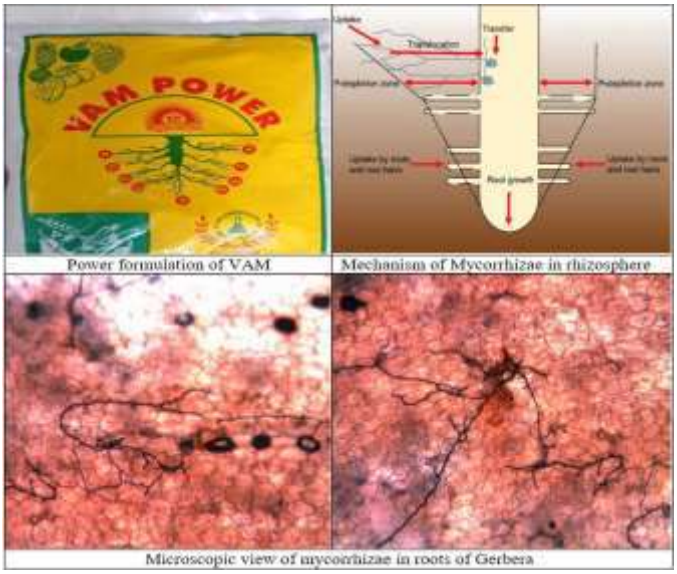
insufficient significance. Complete dependence on the chemical fertilizers for today and tomorrow agricultural production would leads to further loss in soil quality, water contamination and unsustainable burden on the fiscal system. In the naturally existing ecology, rhizospheric soils have innumerable biological living beings to favor the plant development, nutrient assimilation, stress tolerance, disease deterrence, carbon seizing and others. Arbuscular Mycorrhizae (AM) fungi can also potentially strengthen the adaptability of a plant to the changing environment, as a bio-fertilizer. In this context a ray of hope in the form of bio fertilizers has been diffusing all over the agriculture and horticulture, identification of microbes as an alternative source to inorganics is a major breakthrough for aiding the sustainable farming. It is a kind of natural technology implemented by the nature itself for its self-defense against the anthropogenic hazards.

Mycorrhiza is the mutualistic symbiosis (non-pathogenic association) between soil-borne fungi with the roots of higher plants. Two types of mycorrhiza are known today: ecto and endo-mycorrhizas. Benefits from AMF seem to be confined to particular growth periods, namely the seedling stage and during reproduction. Its primary function is the absorption of resources from the soil. The increased efficiency of mycorrhizal roots versus non mycorrhizal roots is caused by the active uptake and transport of nutrients by mycorrhizae. Mycorrhizae are described as improving the absorption of several nutrients. Inoculation with *Glomus mosseae* not only affected plant growth and nutrition in *Medicago sativa*, but also enhanced the activity of *Rhizobium meliloti* when it was applied as an inoculant. AMF have been shown to improve productivity in soils of low fertility and they are particularly essential for increasing the uptake of slowly diffusing ions such as PO_4^{3-}, immobile nutrients such as P, Zn and Cu and other nutrients such as Cadmium. Under drought conditions the uptake of highly mobile nutrients such as NO_3- can also be enhanced by mycorrhizal associations. AM provide essential inorganic nutrients to host plants, thereby improving its growth and yield even under stressed conditions (Chahal *et al.*, 2020). The relative availability of soil N and P, and whether these limit plant growth, are determinants of the extent to which AMF colonization benefits plant nutrient acquisition and growth (Johnson, 2010). AM fungi are especially important for sustainable farming systems because AM fungi are efficient when nutrient availability is low and when nutrients are bound to organic matter and soil particles (Devi *et al.*, 2021).



Power formulation of VAM | Mechanism of Mycorrhizae in rhizosphere

Microscopic view of mycorrhizae in roots of Gerbera

Conclusion

Modern sustainable agriculture demands for a low-input and more nature-based system having role of soil loving mycorrhiza that are able to accelerate plant nutrition, health and soil quality, also under stressful environments.

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Field Diagnosis Techniques and Correction of Physiological Disorders in Rice

S. Ranjith Raja Ram, S. R. Venkatachalam and M. Rajesh

Earlier, the terms physiological disorders were used to refer non-pathogenic sickness of rice. Later investigations revealed that disorders can be attributed to nutrient deficiencies or toxicities to elements or substances. Thus the term nutritional disorder is preferred for indicating non-pathogenic and nutritional related problems. Rice can suffer from various physiological disorders that are not caused by pathogens but rather by environmental factors or nutrient imbalances. These disorders can significantly impact yield and crop quality. Common physiological disorders in rice include iron toxicity, drought stress, and nutrient deficiencies (nitrogen, phosphorus, potassium, etc.). Diagnosis in the field involves observing plant symptoms like leaf discoloration, stunted growth, and reduced tillers, along with understanding the environmental conditions.

Common Physiological Disorders in Rice

Iron Toxicity: Occurs in flooded rice fields where excessive iron is available, leading to leaf bronzing, stunted growth, and reduced nutrient uptake.

Drought Stress: Water scarcity affects various physiological processes, including photosynthesis, transpiration, and nutrient uptake, resulting in reduced growth, leaf wilting, and yield losses.

Nutrient Deficiencies: Deficiencies in nitrogen, phosphorus, potassium, and other essential nutrients can manifest as stunted growth, yellowing of leaves (chlorosis), and reduced tillering.

Field Diagnosis

Visual Symptoms: Observing leaf color, shape and presence of lesions or discoloration can provide clues about the specific disorder.

Environmental Conditions: Considering factors like water levels, soil type and nutrient availability helps in pinpointing the cause.

Growth Stage: The stage of plant development (seedling, tillering, booting, etc.) can be relevant as certain disorders are more prevalent at specific stages.

Nutrient Analysis: Soil and plant tissue testing can confirm nutrient deficiencies or toxicities.

Comparison with Healthy Plants: Comparing affected plants with healthy ones in the same field can highlight the differences in growth and appearance.

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Examples of Field Diagnosis

Iron Toxicity: In flooded fields with high iron levels, reddish-brown or bronze discoloration on leaves is a key indicator.

Drought Stress: Plants under drought stress will exhibit wilting, leaf rolling and reduced biomass.

Nutrient Deficiencies: Nitrogen deficiency may cause yellowing of older leaves, while phosphorus deficiency can lead to reddish-purple discoloration on leaves, according to a report from De Gruyter Brill.

Importance of Field Diagnosis: Accurate and timely field diagnosis is crucial for implementing appropriate management strategies, such as adjusting water levels, applying specific fertilizers, or selecting disease-resistant varieties, to minimize yield losses and improve rice production. Various physiological disorders are considered as constraints for higher productivity in rice (IRRI, 1996). Lowland rice frequently suffers from iron toxicity and is reported to be an important growth-limiting factor in flooded rice (Fageria and Rabelo, 1987).

Causes of Nutritional Disorders in Rice

Nutritional disorders are caused by nutrient deficiency or toxicity of an element or a substance. Under certain circumstances, deficiencies of more than two nutrients are compounded.

Visible Symptoms: In rice some disease symptoms are easily confused with those of nutritional disorders e.g., Blast, Helminthosporium and grassy stunt are the common tropical diseases that produce brown spots on the leaves. It is very difficult to differentiate between zinc deficiency and grassy stunt virus in the early stages of symptom development.

Diagnostic Techniques

Visible Symptoms: It is advisable to observe the major plant parts like plant ht, tillers, leaves and roots.

- ✓ Plant height: Stunted growth is a common symptom for deficiency
- ✓ Reduced tiller number is common.
- ✓ Chlorosis, necrosis (Brown spot) and orange discolouration in leaves
- ✓ The mobility of the nutrients within the plants and the position of the leaf on which the deficiency appears are interrelated.
- ✓ Low mobility of nutrients: symptoms normally appear in upper leaves e.g. iron, boron, calcium.
- ✓ If nutrients are mobile, symptoms appear normally in lower leaves e.g. N, P, K and S.
- ✓ There are two kinds of chlorosis, i) interveinal and ii) uniform. Deficiency of K and Mg causes interveinal chlorosis, whereas N and S results in uniform chlorosis.

When to Observe Symptoms?

Early stages of symptom development are the best time.

Deficiencies of Nutrient Elements

Nitrogen Deficiency

Symptoms

- ✓ Retarded growth of crops
- ✓ Chlorosis of leaves, leaves turn yellowish green and yellow and the whole field looks yellowish

green.

- ✓ The number of culms are very much reduced.
- ✓ At maturity the number of grains per panicle is reduced.

Correction: Foliar application of urea 10 g lit^{-1} at 10 days interval until the symptoms disappear.

Phosphorus Deficiency

Symptoms

- ✓ The number of culms per plant is very few
- ✓ The growth of crop is reduced
- ✓ Leaves turned dark green and stand erect

Correction: Foliar spray of super phosphate (1%) soaks overnight (6 g of super phosphate in 100 lit. of water), decant and spray on the next morning.

Potassium Deficiency

Symptoms

- ✓ Brown and dead spots starting from the middle of the leaves
- ✓ Lower leaves show symptoms

Correction: Foliar spray of KCl @ 5 g lit^{-1} of water at 15 days interval until symptoms disappear.

Low Potassium Induced Iron Deficiency

Symptom: Excessive Fe uptake as a result of insufficient K supply in poorly drained soil may lead to bronzing or browing of leaves

Correction: Foliar spray of KCl @ 10 g lit^{-1} at 10 days interval until symptoms disappear.

Potassium Deficiency in Root, Stem and Panicle

Symptoms

- ✓ Darker colour of potassium deficient roots
- ✓ Thin stem
- ✓ Rotting of leaf sheath in K deficient plants
- ✓ Short flag leaf
- ✓ Short and poorly filled panicle

Correction: Foliar spray of KCI or sulphate @ 5 g lit^{-1} at 15 days interval until symptoms disappear.

Calcium Symptoms: The general appearance of the plant is little affected except when the deficiency is acute. The growing tip of the upper leaves becomes white, rolled and curled. In extreme cases, the plant is stunted and the growing point dies.

Correction: Soil application of gypsum @ 500 kg ha $once^{-1}$ in a year will alleviate the problem

Magnesium

Symptoms

- ✓ Pale yellow strips with green base in boot leaf
- ✓ Poor grain formation

Correction: MgSO @ 5 g lit^{-1} foliar spray at flowering and grain filling stages until the symptoms disappear.

Sulphur

Symptoms

- ✓ Stunted growth
- ✓ Chlorosis of young leaves followed by yellowing of older leaves
- ✓ Reduced tillering
- ✓ Sulphur deficiency affects whole plant whereas N deficiency affects only older leaves

Corrections

- ✓ Sulphur deficiency rarely occur in low land.
- ✓ Application of ammonium sulphate as a partial replacement of urea to correct the deficiency
- ✓ In acute cases, foliar spray of wettable sulphur @ 10 g lit^{-1} of water

Zinc

Symptoms

- ✓ At the base of young leaf on both sides of midrib yellow strips appear.
- ✓ Brown blotches and streaks appear on the lower leaves
- ✓ Leaf size reduced.
- ✓ Uneven growth and delayed maturity

Correction: Foliar application of ZnSO, 0.5% (5 g lit^{-1}) with small amount of sticker twice or thrice at 10 days interval depending on the intensity of deficiency.

Iron

Symptoms

- ✓ Newly emerging leaves become chlorotic
- ✓ In acute cases entire leaves become chlorotic and whitish
- ✓ Deficiency occurs in neutral to alkaline soil
- ✓ More frequent in upland than submerged soil.

Correction: Foliar spray of FeSO @ 5 g lit^{-1} or Ferrous citrate @ 5 g lit^{-1} with small amount of sticker may be applied twice at 15 days interval on the affected plants.

Boron

Symptoms

- ✓ Height is reduced
- ✓ The tips of emerging leaves become white and rolled
- ✓ The growing point may die in severe cases but new tillers con-tinue to be produced in clusters

Correction: Foliar application of borax 2 g lit^{-1} at early stages of symptoms at 10 days interval till symptoms disappear.

High Salt Injury

Symptoms: Growth is stunted and tillering reduced, leaf tips become whitish and frequently some part of the leaves become chlorotic.

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Role of Cry Genes in Crop Protection: A Biotechnological Revolution in Agriculture

Netram, Anushaka Kuntal and Deepak Gupta

Abstract

Transgenic crops, developed through genetic engineering, incorporate foreign genes to enhance traits like insect resistance, herbicide tolerance, and stress resilience. The most notable example is the integration of Cry genes from *Bacillus thuringiensis* (*Bt*), enabling effective pest control while reducing pesticide use. *Bt* crops such as Bt cotton, brinjal, maize, and potato have revolutionized pest management in agriculture. These crops contribute to increased yield, eco-friendly farming, and food security. Modern techniques like Agrobacterium-mediated transformation and gene gun ensure precise gene delivery. Continued research and policy refinement are essential for sustainable adoption of transgenic technologies.

Transgenic crops have emerged as a major breakthrough in modern agriculture. These crops are developed by introducing specific genes into a plant's genome using genetic engineering techniques. One of the most successful examples is the introduction of Cry genes, derived from *Bacillus thuringiensis* (*Bt*), which offer a natural, effective, and environmentally friendly approach to crop protection. A transgenic gene refers to a gene taken from one organism and artificially introduced into another. Accordingly, a transgenic crop is one that contains foreign genes inserted through biotechnological methods to improve its resistance or productivity.

Benefits and Need for Transgenic Crops

Transgenic crops have been developed to overcome the limitations of conventional breeding and to address the growing demands of modern agriculture. One of the foremost advantages of these crops is their insect resistance, which helps reduce crop losses caused by harmful pests. In addition, transgenic crops offer resistance to various plant diseases, ensuring healthier plants and improved productivity. The incorporation of herbicide resistance allows farmers to manage weeds more effectively and reduce the frequency of herbicide applications. Another significant benefit is quality modification, where crops can be genetically tailored for improved nutritional value, taste, shelf life, and processing attributes. These crops are also engineered for tolerance to abiotic stresses such as drought, salinity and extreme temperatures, enabling

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cultivation in challenging environments. Furthermore, transgenic plants have been explored for the production of edible vaccines, offering innovative solutions in public health.

The use of transgenic crops leads to enhanced yield, thereby contributing to global food security, especially in the face of a growing population. They also help in the reduction of cultivation costs by minimizing the need for pesticides and fertilizers. As a result, there is a significant decrease in the use of toxic chemical pesticides, promoting eco-friendly agricultural practices. These combined advantages make transgenic crops a valuable tool in sustainable agriculture and future food systems.

Cry Gene and Its Application in Insect-Resistant Crops: Cry genes, found in the bacterium *Bacillus thuringiensis* (*Bt*), are responsible for producing crystal (Cry) proteins that act as specific insecticidal toxins. These proteins are highly selective, targeting only certain insect species by creating pores in the midgut lining of the insect larvae, leading to cell lysis and death. This unique mechanism has been effectively utilized in developing transgenic crops that are resistant to major insect pests. Each Cry gene encodes a protein with specific toxicity to a narrow group of insects, ensuring minimal impact on non-target organisms. *Bacillus thuringiensis*, a gram-positive, spore-forming bacterium, produces Cry proteins during sporulation. The bacterium was first isolated in 1901 by Shigetane Ishiwatari and was later registered as a pesticide with the Environmental Protection Agency (EPA) in 1961. The integration of Cry genes into crops began with the commercial release of *Bt* cotton in the United States in 1996, followed by its introduction in India in 2002. The use of *Bt* crops has significantly reduced pesticide applications, increased yields, and promoted environmentally friendly farming practices.

Types of Cry Genes and their Target Insects

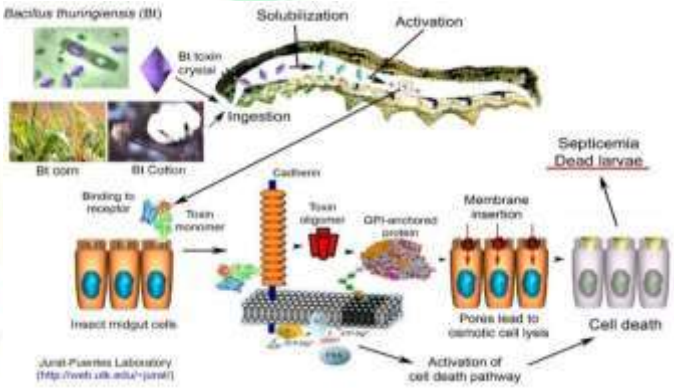
Cry genes from *Bacillus thuringiensis* exhibit insecticidal activity against specific insect orders, making them highly valuable in pest management through transgenic crops. Different Cry genes target different insect groups. For instance, Cry1 group genes such as Cry1Aa, Cry1Ab, Cry1Ac, Cry1B, Cry1C, and Cry1D are effective against insects of the order Lepidoptera (e.g., moths and butterflies). Cry2A and Cry2B target both Lepidoptera and Diptera (e.g., flies and mosquitoes). The Cry3 group (Cry3A, Cry3B, Cry3C) is specific to Coleoptera (e.g., beetles), while Cry4A, Cry4B, Cry4C, and Cry4D target Diptera. Additionally, Cry5 and Cry6 are effective against both Lepidoptera and Coleoptera as well as nematodes, respectively. This specificity allows scientists to tailor pest-resistant crops by introducing the appropriate Cry gene targeting the major pests of that crop.

Methods of Gene Transfer in Plant Genetic Engineering: Gene transfer methods in plants are broadly categorized into vector-mediated and vectorless (direct) approaches. In vector-mediated transformation, foreign genes are delivered into plant cells using biological carriers. The most commonly used method is Agrobacterium-mediated transforma-

tion, where the natural gene transfer ability of *Agrobacterium tumefaciens* is harnessed to introduce desired genes into the plant genome. Another biological method is virus-mediated gene transfer, which employs modified plant viruses as vectors to deliver genes.

On the other hand, vectorless or direct gene transfer methods involve the physical or chemical introduction of DNA into plant cells without using a biological vector. Physical methods include the particle bombardment method (gene gun), where DNA-coated microscopic particles are shot into plant tissues, and microinjection, where DNA is directly injected into plant cells. Chemical methods include PEG (polyethylene glycol)-mediated gene transfer, which facilitates DNA uptake by plant protoplasts through membrane fusion. These diverse methods offer flexibility in genetic engineering depending on the plant species and the transformation efficiency required.

Structure and Mode of Action of Cry Toxin: The Cry toxin, produced by *Bacillus thuringiensis* (Bt), becomes active after undergoing proteolytic cleavage in the insect gut, resulting in three functional domains Domain I, II, and III. Domain I plays a crucial role in pore formation in the insect gut membrane, leading to cell lysis. Domain II is responsible for the recognition and binding to specific receptors on the epithelial cells of the insect midgut. Domain III helps in protecting the toxin from insect gut proteases and contributes to additional receptor binding, enhancing the stability and specificity of the toxin. The mode of action of *Bt* toxin begins when an insect ingests the Cry protein. In the alkaline environment of the insect gut, the protein is solubilized and activated by gut proteases. The activated toxin binds to specific receptors on the midgut epithelium, particularly with the help of Domain II and III. Subsequently, Domain I facilitates pore formation in the cell membrane, causing ion imbalance, cell lysis, and ultimately, death of the insect. This specific mode of action makes *B*t toxins highly effective and environmentally safe for controlling targeted insect pests.



Overview of *Bt* Crops: Advancements in Insect-Resistant Agriculture: Bt crops are genetically engineered to express *Bacillus thuringiensis* (*Bt*) genes that produce insecticidal proteins, offering protection against key insect pests. The first *Bt* crop approved in India was Bt cotton on 26 March 2002, making it the country's first commercial transgenic crop. Bt cotton was introduced in three generations: Bollgard I (MON 531), which included the *cry1Ac* gene providing resistance to pink bollworm; Bollgard II, which incorporated both *cry1Ac* and *cry2Ab* for broader lepidopteran resistance; and the third-generation Bollgard III, which includes *cry1Ac*,

cry2Ab, and *Vip3A*, offering even more comprehensive protection. Several other *B*t crops have also been developed. *Bt* brinjal, aimed at controlling shoot and fruit borer (*Leucinodes orbonalis*), was developed by Mahyco in collaboration with UAS Dharwad, IVRI Varanasi, and TNAU Coimbatore using *cry1Ac* through Agrobacterium-mediated transformation. Varieties include *Bt* Uttara, *Bt* Kajal, and *Bt* Nayantra. *Bt* maize, engineered with *cry1Ab* and *cry9c*, offers effective control of corn borers with up to 96% efficacy. *Bt* potato, launched as NewLeaf® by Monsanto in 1995 using *cry3A* for resistance against the Colorado potato beetle, was eventually withdrawn from the market in 2001 due to limited commercial success. These developments mark significant progress in pest management, though adoption varies globally based on ecological, regulatory, and economic considerations.

Future Prospects and Implications of *Bt* Technology

The future of *Bt* crops extends beyond pest resistance to include enhanced food processing traits and safer transgene markers such as green fluorescent protein and herbicide tolerance genes, replacing traditional antibiotic-resistant markers. While *Bt* crops offer advantages such as improved yield, reduced pesticide use, and protection of beneficial insects, they also pose concerns like higher costs, potential gene flow disruptions, and pest resistance development. In Rajasthan, trends indicate reduced insecticide use even before *Bt* adoption, but with a further decline post-adoption. Overall, *Bt* technology, when integrated with strategies like Integrated Pest Management (IPM), proves to be environmentally safe, user-friendly, and compatible with sustainable agriculture, contributing indirectly to yield gains through reduced pest damage.

Conclusion

Bt crops have significantly transformed pest management in agriculture by reducing reliance on chemical pesticides and enhancing crop productivity. The successful deployment of *Bt* cotton, brinjal, maize, and potato demonstrates the potential of transgenic technology in promoting eco-friendly and sustainable farming practices. However, continuous monitoring, resistance management, and strong biosafety regulations are essential to address environmental and ethical concerns. Integrating Bt crops within broader strategies like Integrated Pest Management (IPM) can ensure long-term benefits, making biotechnology a valuable tool for modern agriculture.

Cultivating Macadamia: Key Insights

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Introduction

Macadamia nut, often referred to as the "queen of nuts," is a highly valued tropical nut crop known for its rich, buttery flavor and high oil content. It belongs to the family *Proteaceae* and the genus *Macadamia*, with *Macadamia integrifolia* and *Macadamia tetraphylla* being the two primary species cultivated commercially. Native to the rainforests of eastern Australia, macadamia has gained global prominence due to its nutritional profile, containing healthy monounsaturated fats, essential minerals like magnesium and manganese, and antioxidants. The nuts are widely used in confectionery, baking, cooking and are also consumed as a premium snack.

Macadamia trees thrive in warm, frost-free climates with well-drained soils and are increasingly being cultivated in regions such as Hawaii, South Africa, Kenya, and parts of India. Despite their long gestation period (taking 5-7 years to bear commercial yield), macadamia orchards can remain productive for several decades, offering long-term economic potential for growers. With increasing demand in global markets and rising awareness of health-conscious diets, macadamia nuts represent a lucrative crop for sustainable horticultural development.

Nutritional powerhouse: Macadamia nuts are not only delicious but also a rich source of essential nutrients, making them a true nutritional powerhouse. These creamy, buttery nuts are packed with heart-healthy monounsaturated fats, which help reduce bad cholesterol levels and support cardiovascular health. They also provide dietary fiber, important for digestive health, and are a good source of essential minerals such as magnesium, manganese and iron. Additionally, macadamias contain antioxidants like tocotrienols and flavonoids that combat oxidative stress and inflammation. Despite being calorie-dense, moderate consumption of macadamia nuts has been linked to improved metabolism, weight

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management and better glycaemic control, making them a smart addition to a balanced diet.

Content of Macadamia Nut Kernels: Macadamia nut kernels are notably rich in fats, with lipids comprising approximately 70% of their total composition making them one of the most fat-dense nuts. The majority of these fats, about 80%, are unsaturated fatty acids, which are known to promote heart health by reducing cholesterol levels and enhancing vascular flexibility. Since the human body cannot synthesize these essential fats on its own, they must be obtained through diet. Although macadamia nuts are a good source of healthy fats, their high caloric value means they should be eaten in controlled quantities.

In addition to beneficial fats, macadamia nuts also offer a range of essential vitamins and minerals that contribute to overall well-being.

Fibre: Macadamia nuts are rich in dietary fibre, which aids in digestion and boosts metabolic function. This fibre also enhances the feeling of fullness and assists the body in flushing out toxins and waste materials.

Vitamin E: With approximately 0.57 mg of vitamin E per 100 grams, macadamia nuts supply about 12% of the daily recommended intake. This powerful antioxidant, often referred to as the "anti-aging" vitamin, helps neutralize harmful free radicals unstable molecules produced due to poor diet, smoking, or stress that damage cells and hinder their renewal.

Vitamins B: Macadamia nuts are a valuable source of various B-complex vitamins, such as B_2, B_3, B_6, and B_9. Notably, they are particularly rich in vitamin B_1 (thiamine), which supports kidney function and aids in the metabolism of carbohydrates. Consuming 100 grams of these nuts can meet around 25% of your daily B_1 requirement.

Magnesium: These nuts are also abundant in magnesium, an essential mineral for maintaining healthy nerves and muscles. A 100-gram serving can provide nearly one-third of your daily magnesium needs. Additionally, macadamia nuts contain calcium and potassium, minerals that play a vital role in maintaining bone strength.

Iron: Iron, present in macadamia nuts, plays a crucial role in oxygen transport by helping bind oxygen to red blood cells. This improves the oxygenation of tissues and organs throughout the body.

Conditions need for macadamia farming

Macadamias are primarily cultivated for commercial purposes and mainly include two key species: *M. integrifolia*, known for its smooth shell, and *M. tetraphylla*, recognized for its rough shell. These species differ in both their climatic requirements and nut characteristics. *M. integrifolia* thrives best in subtropical climates, making it well-suited for the warmer plains and lower hill regions of the North Western Himalayas, such as Kangra, Hamirpur, Una, and Bilaspur. On the other hand, *M. tetraphylla* prefers cooler environments and is a suitable option for cultivation in areas with moderate temperatures offering a climate-based diversification

opportunity for local farmers. A notable hybrid, 'Beaumont', derived from both species, combines the qualities of each and demonstrates strong adaptability across varying temperature ranges. Its resilience and flexibility under diverse climatic conditions have made it a favored choice among growers globally, especially in regions prone to temperature fluctuations.

Macadamia trees thrive in warm, non-humid subtropical climates that have high summer temperatures and mild winters. They prefer fertile, well-drained soils and perform best in areas receiving annual rainfall between 1,000 to 2,000 mm, especially in regions where temperatures do not fall below 10°C. However, once well established, macadamia trees can tolerate light frosts. The optimum temperature for growth is around 25°C. These trees have shallow root systems, making them vulnerable to being uprooted during storms. Therefore, wind protection is essential. Additionally, macadamia trees are susceptible to Phytophthora root rot and may suffer from decline and trunk canker diseases in poorly drained soils. It is important to assess the drainage depth across the orchard site. Locations with a long dry season and light, sandy loam soils having a pH around 5.5-5.7 are generally ideal for cultivation. Macadamia trees usually grow well in areas where guava and orange crops flourish.

Propagation of macadamia: Macadamia is predominantly propagated through grafting, though propagation via rooted cuttings or clonal rootstocks is occasionally practiced. The success of grafting largely depends on the age of the scion wood mature branches typically yield higher graft success rates than younger ones. The use of clonal rootstocks ensures genetic uniformity in orchards, minimizing variation among cultivars. Common grafting methods include splice, side-wedge, and approach grafts for young plants, whereas cleft and bark grafts are more suitable for top-working older trees Russell *et al*. (2016). Seedling rootstocks play a crucial role in influencing tree nutrition, which affects overall tree vigor, size, nutrient uptake, and productivity. These rootstocks are generally favored for their robust root systems and ease of propagation. Among them, *Macadamia tetraphylla* seedlings are often preferred over *M. integrifolia* for their superior root characteristics (Huett, 2004).

In addition to grafting, macadamia can also be propagated via cuttings and air layering. However, these methods can result in weaker root systems, making trees more susceptible to wind damage. The success of rooting in cuttings is influenced by factors such as the use of indolebutyric acid (IBA), bottom heat, seasonal variation, cultivar type, and carbohydrate reserves. Air layering can significantly reduce the juvenile phase by 2.5 to 3 years, enabling earlier fruiting. This technique has been successfully employed in several macadamia-growing regions globally. Despite being labor-intensive and expensive, grafted macadamia plants, particularly *M. integrifolia* and *M. tetraphylla*, are widely sold in Australia, often requiring 12 to 18 months for initial flowering and costing between 14-

29 AUD tree^{-1} (Knight, 2007). In contrast, propagation through cuttings is more cost-effective and allows for rapid clonal multiplication. Semi-hardwood cuttings rooted under mist conditions have demonstrated varying but often satisfactory success rates. However, the narrow genetic base of Hawaiian *M. integrifolia* cultivars presents challenges for broader commercial use.

In South Africa, 'Beaumont' a hybrid of *M. integrifolia* and *M. tetraphylla* is a popular cultivar due to its high yield and ease of propagation through cuttings. While many in the industry favor cuttings over grafted plants, it's recognized that rooted cuttings may develop less extensive root systems compared to grafted or seedling-grown trees. Nonetheless, modified cutting techniques using 3-5 mm thick, 15-20 cm long tip cuttings treated with rooting hormones and planted the same day, have shown promising results. When managed properly, cutting-propagated trees exhibit comparable quality to grafted ones in their first 18 months (Correia *et al.*, 2012). Cuttings offer several benefits including genetic uniformity, absence of graft incompatibility, and no risk of rootstock suckering common issues with seedling rootstocks. Currently, macadamia lacks a formal rootstock breeding program, unlike many deciduous fruit crops. However, ongoing research is evaluating potential rootstocks like *M. jansenii*, *M. tetraphylla*, and their hybrids for traits such as rooting ability, scion compatibility, disease resistance, and yield. These efforts aim to broaden the genetic base of macadamia and enhance the performance of future cultivars.

Flowering Biology: Macadamia has three buds in every leaf axil, each with the potential to develop into shoots or inflorescences (Wilkie *et al.*, 2009). In most cases, only one bud develops per leaf axil. Since *M. integrifolia* bears three leaves per node and *M. tetraphylla* has four, these species and their hybrids typically produce three or four inflorescences node^{-1}. The inflorescence is a drooping raceme that carries between 100 and 300 flowers, with each node of the rachis supporting whorls of six paired flowers (Storey, 1985).

In eastern Australian orchards, flower initiation takes place during late autumn or winter when the minimum temperature ranges from 11 °C to 15 °C (Wilkie *et al*., 2010). After initiation, macadamia buds show minimal growth for about 50-96, likely due to environmental factors such as low temperatures and reduced sunlight. Raceme elongation begins in mid-to-late winter, ad peak flowering typically occurs in late winter or early spring.

Fruit: Once the fruits are harvested, the husking and drying process should be started immediately. After cracking the hard shells, the raw kernels are dried until they reach about 1.5% moisture content, allowing them to be stored safely for nearly a year. Although the kernels can be eaten raw, they are usually roasted and salted before consumption. Roasted nuts are also used in a variety of food preparations and confectionery products.

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Drying Mushrooms: Capturing Flavor, Colour and Nutrition

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Mushrooms are valued worldwide for their rich nutritional content and potential medicinal properties. Mushrooms are quite perishable and deteriorate very quickly after harvesting due to their high moisture content (87-95%). Drying processes are usually used to remove water from mushrooms in order to avoid the growth of spoilage micro-organisms, and biochemical reactions, such as enzymatic activity. Methods such as hot-air, sun, microwave, freeze and osmotic drying effectively reduces microbial growth and extend shelf life. They help to retain mushroom texture, color, flavor and nutritional compounds like proteins, minerals, and antioxidants. Drying also increases shelf stability, reduces weight, and enables the production of mushroom flour, a functional ingredient that can enrich bakery, noodle, and gluten-free products with enhanced protein, fiber, antioxidants, and minerals. Furthermore, when there is an overproduction of mushrooms or they present commercial defects to be consumed in fresh but with quality to be used in food processing, they could be dried to produce flour for human consumption.

Why Dry Mushrooms?

Dehydration is the process of removing moisture or water content from food products to preserve them for longer periods. By reducing the water activity in food, microbial growth, enzymatic reactions, and chemical changes are inhibited, thus preventing spoilage. This process can be achieved through various methods such as hot air drying, freeze drying, or sun drying, depending on the food product and the desired characteristics. Dehydrated foods typically have a longer shelf life, reduced weight for easier transportation, and sometimes concentrated flavors. However, the process of dehydration can also affect the texture, color, and nutritional content of the food (King and Thakur, 2016).

Common Drying Methods: From the warmth of the sun to the hum of a dehydrator, mushrooms can be dried in many ways. Sun drying is the oldest, traditional and most natural method, perfect for sunny days but dependent on weather. Oven drying offers speed and control, while electric dehydrators deliver even results with minimal nutrient loss. Freeze-drying and Osmotic drying captures flavor and nutrition almost as if the mushrooms were never picked.

Nutritional Impact of Drying: As ingredients in products, dried mushrooms are used to increase the nutritional value of the products.

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For example, replacing 5-10% of the flour used to produce noodles and cookies with mushroom powder can increase the contents of protein, dietary fiber, iron, calcium, and potassium in the products. Crushed mushrooms have been added to the dough of bakery products, meat emulsions, and yogurt to improve organoleptic, rheological, and textural qualities (Piskov *et al*., 2022). In some products, mushrooms are used as new ingredients to improve their functional properties, thus, contributing to health promotion, Figure 1. For example, an increase in the antioxidant properties of pasta increases when mushrooms are added to their composition. The addition of mushroom flour to gluten-free bread significantly increases the content of bioactive compounds, antioxidant properties and decrease in glycemic index of bread which may have a positive impact on consumers' health (Kobus *et al*., 2024).

Fig. 1: Functional food

Culinary magic with Dried Mushrooms: Dried mushrooms are a chef's secret weapon. Various value added products have been developed from mushroom such as mushroom mathri (a deep fried snack). They can be soaked to create rich broths, ground into mushroom powder for seasoning, or added directly to soups, stews, and sauces for an instant umai boost. They are perfect for gourmet dishes, (Figure 2) such as: noodles, papads, pasta, candies, pickles, ketch-up, murraba, biscuits, soup powder, nuggets etc (Vlaic *et al*., 2019).

Fig 2: Value added products from mushroom powder

Conclusion

From extending shelf life to intensifying taste, drying mushrooms offers a perfect blend of practicality and flavor mastery. It preserves their valuable nutrients, enhances their earthy umami flavor, and makes them available year-round without losing quality. Whether done under the sun, in a tray dryer, microwave drying or through advanced freeze-drying, each method delivers the same reward, mushrooms that carry their forest-fresh aroma and nutrition straight to your plate, no matter the season.

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Chelated Fertilizers: Their Importance and Effectiveness

Mrinal Choudhury, Khanin Pathak and Britan Rahman

Introduction

Plant nutrients are essential for crop growth and development. Proper management of plant nutrient is crucial for optimal crop productivity. As of now seventeen elements have been identified as essential plant nutrients. The essential elements are further categorized as macronutrients and micro-nutrients depending on the amount required by the plant. Macronutrients are required in large amounts by the plants while the micronutrients are required in comparatively smaller quantities. In general, those nutrients in concentrations of ≤ 100 parts per million (ppm) in plant tissues are termed as micronutrients and include iron (Fe), zinc (Zn), manganese (Mn), copper (Cu), boron (B), chlorine (Cl), molybdenum (Mo), and nickel (Ni). Many micronutrients like Fe, Mn, Zn, and Cu are easily oxidized or precipitated in soil and are not very efficiently utilized by the plants. To overcome this problem chelated fertilizers have been developed so that the micronutrients can be utilized efficiently. This article presents an overview of chelated fertilizers and considerations for their optimal use in commercial crop production.

Chelates and chelated fertilizers

The word chelate is derived from the Greek word chele, which refers to a 'crab's claw'. Hence, chelate refers to the pincer-like manner in which a metal nutrient ion is encircled by the larger organic molecule. The larger organic molecule that capture the metal ion is usually called a ligand or chelator. A list of common natural or chemical synthetic ligands (Havlin *et al*., 2005; Sekhon 2003) is provided in Table 1. A chelated fertilizer if formed when each of the listed ligands or chelators is combined with a micronutrient. Chelated micronutrients are protected from oxidation, precipitation, and immobilization in certain conditions because the organic molecule (the ligand) can combine and form a ring encircling the micronutrient. The pincer-like manner in which the micronutrient is bonded to the ligand changes the micronutrient's surface property and favours the uptake efficiency of applied micronutrients.

Necessity of chelated fertilizers: In the hetero-geneous and complex soil environment most of the micronutrient ions are oxidized and precipitated. This process drastically reduces their bioavailability and plants suffer from micronutrient deficiency. Chelation keeps a micronutrient from undesirable reactions in solution and soil. The chelated fertilizer (Table 2) improves the bioavailability of micro-nutrients such as Fe, Cu, Mn, and Zn, and in turn contributes to the productivity and profitability of commercial crop production. Chelated fertilizers have a greater potential to increase commercial yield than regular micro-nutrients if the crop is grown in low-micronutrient stress or soils with a pH greater

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Table 1: Common synthetic and natural chelate compounds (ligands)

Abbreviation	Name	Formula
CDTA	Cyclohexanediaminepentaacetic acid	$C_{14}H_{22}O_8N_2$
CIT	Citric acid	$C_6H_8O_7$
DTPA	Diethylenetriaminepentaacetic acid	$C_{14}H_{23}O_{10}N_3$
EDDHA	Ethylenediaminediaminedi-o-hydroxyphenylacetic acid	$C_{18}H_{20}O_6N_2$
EDTA	Ethylenediamintetraacetic acid	$C_{10}H_{16}O_6N_2$
EGTA	Ethylene glycol bis(2-aminoethyl ether) tetraacetic acid	$C_{14}H_{24}O_{10}N_2$
HEDTA	Hydroxyethylenediaminetriacetic acid	$C_{10}H_{18}O_7N_2$
NTA	Nitrilo-triacetic acid	$C_6H_9O_6N$
OX	Oxalic acid	$C_2H_2O_4$
PPA	Pyrophosphoric acid	$H_4P_2O_7$
TPA	Triphosphoric acid	$H_5P_3O_{10}$

(Source: Havlin *et al*., 2005; Sekhon, 2003)

than 6.5. In order to grow a good crop, crop nutrient requirements (CNRs), including micronutrients, have to be satisfied first from the soil. If the soil cannot meet the CNR, chelated sources need to be used. Natural organic materials have approximately 0.5% Cu (Table 2). This approach benefits the plant without increasing the risk of soil and ground water pollution.

Table 2: Chelated fertilizers, formula and nutrient content (%)

Source	Formula	Nutrient (w/w, %)
Iron chelates	NaFeEDTA	5-14
	NaFeEDDHA	6
	NaFeDTPA	10
Copper chelates	$Na_2CuEDTA$	13 Cu
	$Na_2CuHEDTA$	9
Manganese chelates	$Na_2MnEDTA$	5-12 Mn
Zinc chelates	$Na_2ZnEDTA$	14 Zn
	$Na_2ZnHEDTA$	9-13 Zn
Natural organic materials	-	5-10 Fe 0.5 Cu 0.2 Mn 1-5 Zn

Factors affecting bioavailability of micronutrients

The bioavailability of micronutrients depends on several factors related to soil, plant and the environment. For example, several factors reduce the bioavailability of iron, including high soil pH, high bicarbonate content, plant species and abiotic stresses. Interestingly, grass species are usually more efficient than other species because they can excrete effective ligands. Plants typically utilize iron as ferrous iron (Fe^{2+}). Ferrous iron can be readily oxidized to the plant-unavailable ferric form (Fe^{3+}) when soil pH is greater than 5.3 (Morgan and Lahav 2007). Iron deficiency often occurs if soil pH is greater than 7.4. Chelated iron can prevent this conversion from Fe^{2+} to Fe^{3+}. Table 3 depicts the relationship between soil pH and chelated fertilizer requirements in commercial crop production.

Table 3: Soil pH and chelated fertilizer requirements in commercial crop production

Soil pH < 5.3	Soil pH ranges from 5.3 to 6.5	Soil pH > 6.5
No chelated fertilizers are needed.	Chelated fertilizers may be needed.	Chelated fertilizers are needed.
At soil pH 5.3 or lower, soil can generally provide sufficient micronutrients. In the soil pH range from 5.3 to 6.5, highly susceptible crop species may need chelated fertilizers. At soil pH 6.5 or greater, most crops need chelated fertilizers.		

Role of chelates in enhancing bioavailability of micronutrients

Applying nutrients such as Fe, Mn, Zn, and Cu directly to the soil is inefficient because in soil solution they are present as positively charged metal ions and will readily react with oxygen and/or negatively charged hydroxide ions (OH^-).

If they react with oxygen or hydroxide ions, they form new compounds that are not bioavailable to plants. Both O and OH ions are abundant in soil and soilless growth media. The ligand can protect the micronutrient from oxidization or precipitation. For example, the oxidized form of iron is ferric (Fe^{3+}), which is not bioavailable to plants and usually forms brown ferric hydroxide precipitation ($Fe(OH)_3$). Ferrous sulfate is often used as the iron source. Its solution should be green. If the solution turns brown, this indicates that the bioavailable form of iron is oxidized and therefore unavailable to plants. In the soil, plant roots can release exudates that contain natural chelates. The non-protein amino acid (mugineic acid) is one such natural chelate produced by graminaceous (grassy) plants grown in low-iron stress conditions. The exuded chelate works as a vehicle, helping plants absorb nutrients in the root-solution-soil system (Lindsay, 1974). A plant-excreted chelate forms a metal complex (*i.e.*, a coordination compound) with a micronutrient ion in soil solution and approaches a root hair. In turn, the chelated micronutrient near the root hair releases the nutrient to the root hair. The chelate is then free and becomes ready to complex with another micro-nutrient ion in the adjacent soil solution, restarting the cycle. The process works like this:

- ✓ A chelate is exuded from a root to the soil solution.
- ✓ The chelate complexes a micronutrient (e.g., iron) from the soil solution.
- ✓ The chelated micronutrient is carried to a root hair, where it is released.
- ✓ The chelate goes back to the soil solution and starts another cycle.

Foliar application of chelated fertilizers

To avoid the chemical reactions between micronutrient chelates and soil, it is preferred to apply the chelated fertilizers as foliar spray. Chelated nutrients also facilitate nutrient uptake efficiency for foliar application because crop leaves are naturally coated with wax that repels water and charged substances, such as ferrous ions. The organic ligand around the chelated micronutrient can penetrate the wax layer, thus increasing iron uptake. Chelated iron fertilization is significantly more effective and efficient compared to traditional iron fertilization. Chelated fertilization can improve micronutrient use efficiency and make micronutrient fertilization more cost effective.

Vegetable and fruit crop susceptibility to micronutrients differs significantly. For those in the highly or moderately susceptible categories, chelated fertilizers are often needed. Generally, for those with low susceptibility, no chelated fertilizers are needed unless the soil is low in micronutrient bioavailability, as demonstrated by a soil test. Soil pH is a major factor influencing micronutrient bioavailability; therefore, if soil pH is greater than 6.5, then the soil may have limited micronutrient bioavailability (Poh *et al.*, 2009), and chelated fertilizers may be needed.

Selection of chelated fertilizer

Each of the ligands (Table 1) can form a chelated fertilizer with one or more micronutrients.

The effectiveness and efficiency of a particular chelated fertilizer depends on the pH of the plant growth medium. The ligands EDTA, DTPA, and EDDHA are often used in chelated fertilizers. Their effectiveness differs significantly. Generally speaking, EDDHA chelated Fe is most stable at soil pH greater than 7.0. Chelated fertilizer stability is desired because it means the chelated micronutrient will remain in a bioavailable form for a much longer period of time. It will increase the micronutrient use efficiency by the crops. The stability of chelated Fe fertilizers varies at different pH conditions. Table 3 shows the relationship between soil pH and chelated fertilizer requirement.

Table 4: Few examples of chelated fertilization rates for selected commercial vegetable and fruit crops (Adopted from Havlin *et al*., 2005)

Crop	Nutrient Rate	Source
Iron		
Vegetables	500-1000 g/400 L water ha^{-1}	Iron chelates
Deciduous fruits	100-200 g/100 L water ha^{-1}	Iron chelates
Citrus	30-50 g/7.5-20 L water $tree^{-1}$	Iron chelates
Copper		
Corn	800 g/400 L water ha^{-1}	$Na_2CuEDTA$
Manganese		
Vegetables	100-250 g/750 L water ha^{-1}	$Na_2MnEDTA$
Zinc		
Pecan	125-250 g Zn/400 L water ha^{-1}	$Na_2ZnEDTA$

Correction of Fe deficiency depends on individual crop response and many other factors. For instance, for vegetables, the rate is usually 500-1000g chelated Fe in 400 liters of water per hectare. Deciduous fruits need 100-200g chelated Fe in 100 liters of water per hectare (Table 4). Foliar application is more effective than soil application. For foliar application, either inorganic or chelated Fe is effective, but for fertigation, chelated Fe should be used. In high pH soil, crops are also vulnerable to Cu deficiency. Chelated Cu is significantly more effective than inorganic Cu. A commonly used copper chelate is $Na_2CuEDTA$, which contains 13% Cu.

In addition to soil pH, Mn is also influenced by aeration, moisture, and organic matter content. Chelated Mn can improve Mn bioavailability. Mn deficiency occurs more often in high pH and dry soil. Similar to other micronutrients, foliar spray is much more effective than soil application. For commercial vegetable production, 0.2-0.5 kg MnEDTA in 650 litres of water per hectare can effectively correct Mn deficiency (Table 4). Zinc is another micronutrient whose bioavailability is closely associated with soil pH. Crops may be susceptible to Zn deficiency in soil with pH > 7.3. Spraying 0.10-0.14 kg chelated Zn in 400 litres of water per hectare is effective (Poh *et al*., 2009). Animal waste and municipal waste also contain Cu, Mn, and Zn micronutrients (Table 4).

Summary

- ✓ High pH soil (pH > 6.5) often has low bioavailability in micronutrients such as Fe, Mn, Zn, and Cu, and micronutrient fertilizers are needed for commercial crop production.
- ✓ Crop susceptibility to the above micronutrients depends on the species and cultivar. Commercial crops can be categorized into three susceptibility groups: high, medium, and low. The first two groups often need chelated fertilizers.
- ✓ Inorganic water-soluble micronutrient application to the soil is often ineffective for correcting

micronutrient disorders.

- ✓ Chelated fertilizers are less reactive to soil conditions and can significantly enhance nutrient uptake and utilization efficiencies.
- ✓ Chelate fertilization rates range from 0.2 to 1 kg micronutrient ha^{-1} for vegetable production and 0.1-0.5 kg micronutrient ha^{-1} for fruit production.
- ✓ Foliar application of chelated fertilizers is often more effective than soil application.

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Farming with Hydrogel: A Game Changer for Climate-Resilient Crops

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Introduction

In the face of escalating climate challenges rising temperatures, erratic rainfall, and recurring droughts ensuring agricultural sustainability has become a global imperative. Traditional farming practices are struggling to meet the food demands of a growing population while coping with unpredictable weather patterns. Water management is one of the most pressing challenges in agriculture today, particularly as climate change exacerbates droughts and water scarcity in many regions. The successful delivery of accessible water services under projected climate change impacts, therefore, lies with an extension of the adaptive water management approach to include equitable access as a key driver (Mukheibir, 2010). Water stress, driven by factors such as climate change, population growth, and unsustainable agricultural practices, has become a critical challenge for global food security. Water stress occurs when the demand for water exceeds the available supply during a certain period, or when poor quality restricts its use, leading to adverse impacts on agricultural productivity. Agricultural systems, especially those in arid and semi-arid regions, are increasingly vulnerable to water scarcity resulting in reduced crop yields, soil degradation, and economic instability. One innovative solution gaining increasing attention in agricultural research and field applications is the use of hydrogels water-absorbent polymers with the potential to transform modern farming and enhance climate resilience. They act as water reservoirs, absorbing and retaining moisture from rainfall or irrigation and gradually releasing it as the soil dries out. To improve soil moisture availability by reducing evaporation losses and retaining moisture in the effective rooting zone, hydrogel is found to be a promising methodology in drought-prone areas (Ashraf *et al.*, 2021). This unique capability improves soil moisture retention, making hydrogels particularly valuable in arid and semi-arid regions where water resources are limited.

Properties of Hydrogel

Hydrogels are macromolecular substances that exhibit unique properties intermediate between solids and liquids. They can undergo significant volume changes in response to external stimuli such as temperature and pH. Typically derived from petroleum-based sources, superabsorbent polymers (SAPs) are widely used in agriculture to enhance water retention in arid soils, as they can absorb many

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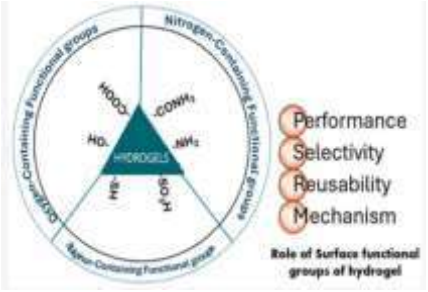
times their weight in water. These water-absorbent polymers possess the ability to retain substantial amounts of moisture and nutrients (Manimaran and Aswitha, 2024). The performance of hydrogels is influenced by factors such as cross-link density and the presence of hydrophilic functional groups, enabling them to act as effective soil conditioners that improve nutrient transfer and irrigation efficiency (Tariq *et al.*, 2023). Their water-holding capacity is particularly affected by the presence of hydrophilic groups such as hydroxyl (-OH), carboxyl (-COOH), amide (-$CONH_2$), amino (-NH_2), thiol (-SH), and sulfonic acid (-SO_3H), as shown in Figure 1 (Source: Ali, *et al.,* 2024). These groups enhance the hydrophilicity of the polymer network, facilitating better interaction with water molecules and improving the hydrogel's swelling and water retention capabilities.



Role of Surface functional groups of hydrogel

Application of Hydrogel in Agriculture

Hydrogels have various applications in agriculture, due to their ability to absorb, retain, and slowly release water, making them invaluable in water-scarce environments.

Soil Moisture Enhancement: Hydrogels can absorb water during irrigation or rainfall and gradually release it into the soil as it dries out, ensuring a steady supply of moisture to plant roots.

Nutrient Delivery and Fertilizer Efficiency: hydrogels can create controlled-release systems that deliver nutrients in response to soil moisture levels. It improves fertilizer use efficiency and reduces nutrient leaching.

Seed Coating and Germination Enhancement: Hydrogels are used in seed coating to improve germination rates and seedling establishment.

Erosion Control and Soil Stabilization: Hydrogels help bind soil particles together, reducing the risk of erosion caused by wind and water

Integration with Precision Agriculture: In precision agriculture, hydrogels enhance crop performance and contributes to more sustainable farming practices by minimizing inputs and reducing environmental impact.

Table 1: Summarizing the overview applications of selected hydrogel in agriculture

Hydrogel Type	Application	Benefits to Agriculture
Polyacrylamide (PAM)	Soil amendment	Improves soil structure and crop yield
Starch-based Hydrogel	Seed coating, drought-prone soils	Enhances germination and early seedling vigor
Cellulose-based Hydrogel	Mulching, root zone moisture control	Reduces irrigation frequency and nutrient leaching
Chitosan-based Hydrogel	Controlled fertilizer release	Improves fertilizer efficiency and crop health
Agar/Agarose Hydrogel	Tissue culture and nursery propagation	Promotes uniform plantlet development
Gelatin-based Hydrogel	Biocarriers for microbial inoculants	Boosts soil microbial activity and plant growth
Synthetic Superabsorbent Polymer (SAP)	Arid region farming	Enhances drought resistance and plant resilience
Hybrid Hydrogel (e.g., PAM + natural polymer)	Smart irrigation systems	Supports sustainable agriculture practices

Hydrogels as a Catalyst for Improved Plant Growth and Stress Tolerance: In water-scarce regions, hydrogels play a crucial role in enhancing plant growth and stress resilience by improving soil moisture retention, nutrient availability, and overall soil structure. Hydrogels offer a promising solution to the growing shortage of freshwater for agriculture by increasing soil and water productivity without degrading the environment or depleting natural resources. By absorbing and retaining substantial amounts of water, hydrogels swell within the soil matrix, thereby increasing its water-holding capacity and delaying the onset of plant wilting under drought conditions. They positively influence key soil physical properties such as permeability, density, structure, and texture, and regulate evaporation and infiltration rates, leading to more efficient water use. This prolonged water availability significantly improves plant survival and performance during periods of water stress. Furthermore, hydrogels release stored water and nutrients gradually to the plants when the moisture level in the root zone declines, ensuring sustained plant nourishment. Moreover, hydrogel application has been associated with a reduction in fruit drop, and under varying stress intensities, it can lead to increased total yield and fruit weight. The improved soil environment also promotes more extensive root development, enhances plant biomass, and ultimately contributes to higher and more stable crop productivity.

Conclusion

Hydrogels represent a transformative and sustainable innovation in modern agriculture, providing effective solutions to pressing challenges such as water scarcity, soil degradation, and climate-induced stress. The application of hydrogels in arid and semi-arid regions improves soil properties, increases the water-holding capacity of soil, improves irrigation efficiency, boosts the growth of various crops, and ultimately enhances crop water productivity. They also create a conducive environment for robust root development in well-drained soils, contributing significantly to yield improvement. Owing to their chemical and physical structures, hydrogels can serve as effective absorbents in environmental preservation by functioning as water retainers, soil conditioners, and nutrient carriers in the agricultural sector. In the context of increasing environmental uncertainties, the adoption of hydrogel technology is not merely advantageous it is imperative for advancing climate-resilient and future-ready farming systems.

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Vermicompost: Turning Waste into Soil Wealth

Ajmala Jabin

Introduction

Vermicomposting is emerging as an innovative, eco-friendly solution for transforming organic waste into valuable soil conditioner. With increasing concerns over soil degradation and chemical fertilizer overuse, harnessing earthworms to recycle kitchen scraps, farm residues and livestock manure has become a sustainable strategy to improve soil fertility. Vermicompost production not only reduces landfill burden but also supports organic farming practices that benefit farmers, consumers and the environment.

What is Vermicomposting?

Vermicomposting is a process by which all types of biodegradable waste such as kitchen waste, livestock waste, farm waste, organic industrial waste etc. are converted to nutrient rich vermicompost by the activity of earthworm on biowaste. Among the various species, *Eudrilus eugeniae* and *Eisenia fetida* are the most commonly used for this purpose due to their high efficiency in decomposing organic matter.

Eudrilus eugeniae

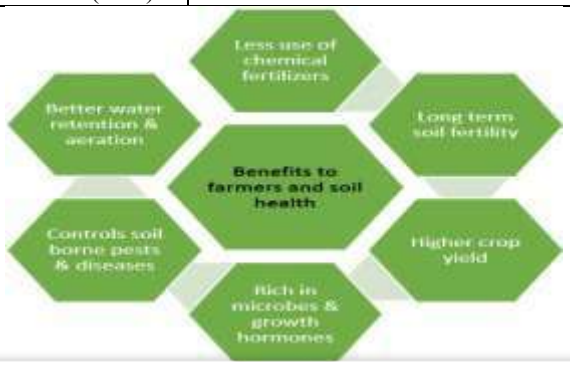
Eisenia fetida

How to Start Vermicomposting at Home or Farm

A vermicomposting unit can be set up in earthen pits or cement tanks, ideally about 2.5 m long, 1 m wide, and 0.3 m deep. A layer of coconut husk is placed at the bottom, with the concave side facing upward, to aid aeration and drainage. Moisten the husk, then add a mix of organic biowaste and cow dung in an 8:1 ratio, filling the pit until the material is about 30 cm above ground level. Let it partially decompose for 7-10 days, then introduce 500-1000 earthworms (about 0.5-1 kg) into each pit. Cover the setup with a thatched roof to protect it from direct sunlight and rain. In about 60-75 days, you'll have rich, dark compost ready to harvest. When the compost is ready, it is removed from the pit and placed in a shaded, airy location for 2-3 hours to allow excess moisture to evaporate. Worms and undecomposed material are separated and returned to the pit for next cycle.

Nutritional Value of Vermicompost

Nutrient	Approximate Content (% dry weight)
Nitrogen (N)	1.2-1.5%
Phosphorus (P_2O_5)	0.4-0.8%
Potassium(K_2O)	1.0-1.8%



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Vermicompost is rich in humus, contains micronutrients in trace amounts and generally has a near-neutral pH, making it ideal for healthy plant growth.

Favourable Conditions for Earthworm

pH: 6.5-7.5

Moisture: 60-70%

Aeration: 50% pore space

Temperature: 18-35°C

Maintaining these conditions is essential for efficient composting.

Precautions during Vermicomposting

- ✓ Do not cover beds with plastic sheets, as this traps heat and gases.
- ✓ Avoid waterlogging and excessive dryness.
- ✓ Keep acidic wastes (citrus peels, onions) minimal.
- ✓ Ensure proper drainage to prevent foul odours.

Vermiculture: Multiplying Earthworms: For large-scale operations, mass multiplication of earthworms is crucial. A 1:1 mix of cow dung and decaying leaves is used to culture worms in shaded cement tanks or buckets. Regular sprinkling keeps moisture stable, and within 1-2 months, the worm population can multiply up to 300 times, supplying starter cultures for multiple vermicompost units.

Conclusion

Vermicomposting offers a practical, low-cost and environmentally friendly way to convert farm and household waste into “black gold” for the soil. Farmers adopting this technique can improve their livelihoods while promoting soil health and sustainability. As awareness grows, vermicompost is poised to become a cornerstone of organic agriculture and a vital tool in India's journey towards sustainable farming.

A Peek into the Potassium Dynamics in Soil-Plant System

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Prologue

Every plant needs seventeen essential elements for proper growth and development. Based on their requirement by the crop, these elements are classified as major elements and micronutrients. Considering its key role in crop production potassium is regarded as major nutrient element. Among the major nutrient elements, potassium (K) is usually the most abundant in soils. Most of the mineral soils generally contain K in the range between 0.04 and 3%. Potassium is involved in large number of physiological processes in plants like osmoregulation, cation-anion balance, protein synthesis and activation of enzymes. Way back in 1840, the Father of Agricultural Chemistry, Justus Von Liebig recognized K as one of the major plant nutrients played a key role in soil fertility and he developed K mineral fertilizers to increase crop yields. However, though these findings are as relevant today as they were then, long term policy for sustaining potassium level in the soil with adequate supply in the form of manures and fertilizers is quite often neglected.

In India majority of the farming areas are rainfed. The frequent and prolonged droughts are the major concern for Indian farmers. Inadequate rainfall and insufficient moisture storage capacity of the soils in many parts of the country lead to poor performance of the crops. A major consequence of decline in soil fertility in agricultural land is the greater prevalence of sustained periods of moisture deficiency resulting from poorer water storage throughout the soil profile. The increasing events of moisture and other abiotic stresses arising from loss of soil fertility as well as global warming will necessitate a specifically high supply of potassium for stress mitigation. In this article an attempt has been made to explain various forms of potassium in soil and the role of the element in plants. The mechanisms though which potassium ion equilibrium is maintained in the soil-plant system, its functions and deficiency symptoms in plants, its role in human health etc. will be explained in the subsequent articles.

Potassium in Soil

As a general consensus it is accepted that potassium exists in four forms in soils: structural or mineral K (Min-K), non-exchangeable or fixed K (Fixed-K), exchangeable-K (Ex-K) and K in soil solution (Sol-K). Based on various literatures it is understood that K availability is dependent on existence of four distinct K pools differing in accessibility to plant roots with reversible transfer of K between the pools. Accordingly, it is believed that there are equilibrium and kinetic reactions between the four forms of soil K that affect the level of soil

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solution K at any particular time, and thus, the amount of readily available K for plants. Soil solution plays a pivotal role in providing the pathway for K uptake from the soil to plant roots. Although this pool constitutes only a very small fraction of total K in soil (0.1-0.2% of the total soil K), representing only about 5% of total crop demand at any given time, it is immediately available and replenished by both the exchangeable K (Ex-K, readily plant available K) and the slowly or non-exchangeable K (Fixed-K, slowly plant available K) pools. Ex-K and Fixed-K make up about 1-2% and 1-10% of the total K, respectively and are the main contributors to K uptake by plants. The exchangeable fraction (EK) i.e. the K held on negatively charged sites of clay mineral and soil organic matter is in rapid equilibrium with soil solution K and is considered to be readily available to plants. Its measurement, can often, but not always, provides a useful indicator of K soil status in relation to plant supply. Potassium is released from the slowly or non-exchangeable K pool (SEK) from lattice wedge sites of weathered micaceous clay minerals which are selective for K ions. The remaining pool which holds the bulk of K (90-98% of the total soil K) , is held in the structure of the primary K bearing minerals, such as micas and feldspars being released very slowly by weathering to replenish the EK and SEK pools. Exchangeable and soil solution K are often considered available to plants, while fixed or structural K are only slowly or potentially available. The total soil K (Tot-K) pool constitutes a large K-resource between 3,000 and 1,00,000 kg ha^{-1} in the upper 20 cm of the soil profile depending on parent material, soil type, and mineralogy. However, the availability of this soil K for crop depends on the ability of the soil to release K and on the crop itself. Several studies have shown that release of K from the structural or the fixed fractions can contribute significantly to plant supply. Dynamic equilibrium reaction exist between the phases of soil K, hence all factors that affect these equilibrium reactions will indirectly affect the size of the different K forms (Fig. 1).

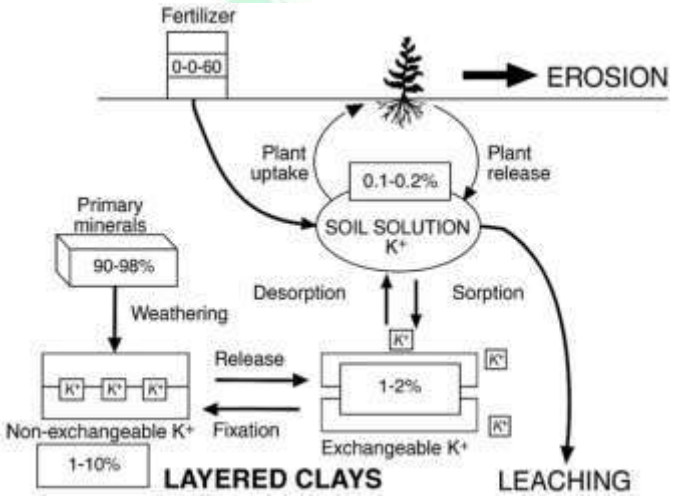

Fig. 1: K-Cycle

There exist various methods to determine the amount of available K present in the soil. At the same time, various methods are also employed to determine the fertilizer (potassic) doses for various crops (and varieties) based on the crop requirement and the amount of potassium estimated as available in the soil for the crop. The most common method used worldwide to assess the K status of a soil for the likelihood of obtaining a response in crop yield to fertilizer applications is the measurement of exchan-

geable K. However, the major limitation with this method involving use of 1 N ammonium acetate solution for extracting available K pool of the soil lies in the fact that it completely ignores the remarkable differences in the abilities of soils to replenish exchangeable K pool when it gets depleted.

Potassium in Plants

Potassium is the most abundant inorganic cation in plant tissues. In adequately supplied plants it may make up about 6% of the dry matter or concentration of about 200 mM. Potassium is unique as a plant nutrient as it occurs exclusively in the form of the free ion. Besides its vital importance for enzymatic process and ATP synthesis, K has a specific physiological role in plants in the opening and closing of stomata through its influence on the osmotic potential of the guard cell. This makes potassium deficient plants more susceptible to drought than plants with an adequate K supply. Adequate K supply also increases the ability of plants to tolerate low temperatures and can protect plants from frost injury and winterkill. Good K supply is also important to enhance disease resistance of crops. Hence, low crop K concentrations could impact on the robustness of the cropping system before being recognizable as a crop K deficiency. Under k deficiency cytosolic K activity is maintained at the expense of vacuolar K activity. Highest concentrations of K are found in young developing tissues and reproductive organs indicative of its high activity in cell metabolism and growth. K activates numerous enzymes including those involving in energy metabolism, protein synthesis, and solute transport. In cells, K is needed in the maintenance of transmembrane voltage gradients for cytoplasmic pH homeostasis and in the transport of inorganic anions and metabolites. In long distance transport, K is the dominant cation within the xylem and phloem saps neutralizing inorganic and organic anions, conferring high K mobility throughout the entire plant. Uptake and accumulation of potassium by plant cells is the primary driving force for their osmotic expansion.

Plant species differ in their K needs and they also have different abilities to take up K. Generally, monocotyledons like cereals exploit K reserves better than dicotyledons such as potatoes and legumes. Pasture legumes have been shown to be more susceptible to K deficiency than cereals. Root hairs can double the surface area of the root system and can therefore contribute substantially to the uptake of nutrients, especially those with low mobility and high demand such as K.

Mild K deficiency in crops does not immediately result in visible symptoms because of the high rate of redistribution between mature and developing tissues. At first there is only a reduction in growth rate (hidden hunger0 and only later do chlorosis and necrosis begin in the more mature leaves. In many crop species including maize and fruit trees these symptom begin in the more mature leaves. In many crop species including maize and fruit trees these symptom begin in the margin and tip of the leaves but in others including some legumes irregularly distributed spots occur on the leaves.

Plants suffering from K deficiency show decrease in turgor and become flaccid under wter stress particularly during the mid day period. Plant roots sense changes that occur after the onset of K deficiency but no major changes take place in biomass partitioning or root architecture as occurs under N and P deficiency. Arabidopsis roots respond to K deficiency by upregulation of high affinity K influx systems and the production of respective oxygen species (ROS) and ethylene, ROS being accumulated in discrete regions of the root that have been active in K uptake and translocation. Applications of K or high native K concentration in soils may reduce levels of Ca, Mg, Zn, Al and Mo in plant tissues. The reduction of Mg levels in the tissue with K is of particular importance since grass tetany may result from low Mg concentration in forage crops.

Epilogue

It is well known that our country is completely lacking potassic mineral resources and has to entirely depend upon import for meeting the requirement of potash for agriculture usage. In India animal dung and crop residues are used as a source of bioenergy for cooking and heating without recycling the K rich ash or sludge back to farm land which receives only low, if any, input of K fertilizers (Hasan, 2002). The inadequate recycling of potassium in Indian Agriculture thus puts these soils and the crops they carry at risk. Therefore, it is evident from the above that replenishment of potassium with adequate supply as chemical fertilizers and organic manures as well as recycling of organic residues is vital for sustainable crop production.

Boosting Mungbean Yield through Quality Seed Production

Ghanprakash Ghoretha, Deepak Gupta and Chelsi

Abstract

Boosting mungbean yield through quality seed production requires the use of genetically pure, disease-free, and high-germination seeds to ensure a uniform and vigorous crop stand. Proper isolation during seed production prevents genetic contamination, while timely sowing and recommended agronomic practices enhance crop performance. Scientific seed processing, including cleaning, grading, and treatment, further improves seed quality and storability. Adoption of certified seeds by farmers results in better germination, healthier plants, and higher yields. This approach not only improves productivity but also enhances profitability and sustainability in mungbean cultivation.

Mungbean (*Vigna radiata* L. Wilczek) is a short-duration, high-protein pulse crop widely cultivated in India and other parts of Asia. It is valued for its rich nutrient profile, including proteins, amino acids, vitamins, and minerals, and plays a significant role in vegetarian diets and low-income households. In addition to its nutritional value, mungbean improves soil fertility through biological nitrogen fixation, making it a key component of sustainable farming systems. Despite its potential, yields often remain below optimal levels, mainly due to the use of low-quality or genetically impure seed. Quality seed production is, therefore, one of the most effective strategies to boost productivity and ensure varietal purity.

Importance of Quality Seed in Mungbean

Quality seed serves as the foundation for high crop yields. Studies have shown that the use of genetically pure, high-germination seed can increase yields by 15-25% compared to farm-saved seed. In mungbean, quality seed ensures:

- ✓ Genetic purity of the selected variety.
- ✓ High germination and vigor, resulting in uniform crop stands.
- ✓ Resistance to pests and diseases if improved varieties are used.
- ✓ Better adaptability to specific agro-climatic conditions.

Stages of Quality Seed Production in Mungbean

Selection of Suitable Variety

Selecting the right variety is the most critical step in quality seed production.

Criteria for selection

- ✓ High yield potential and early maturity to fit into short cropping windows.
- ✓ Resistance to major diseases like Yellow Mosaic

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Virus (YMV), Cercospora Leaf Spot, and powdery mildew.

- ✓ Desirable seed traits such as boldness, uniform color, and lustre to meet market preferences.
- ✓ Suitability to the local climate and soil conditions.

Land Requirement and Isolation Distance

For pure seed production, field selection and isolation are essential.

Field selection: Choose fertile, well-drained loamy or sandy loam soil with neutral pH Avoid fields with heavy weed infestation or volunteer plants from the previous crop.

Previous crop consideration: Avoid growing mungbean after another mungbean crop in the same field to prevent volunteer plants and disease carryover.

Isolation distance: Although mungbean is predominantly self-pollinated, a minimum 10 meters isolation from other varieties or off-type plants prevents accidental cross-pollination and genetic contamination.

Seed Source

- ✓ Seed purity starts from the source.
- ✓ Always use Breeder seed (produced under direct supervision of scientists) or Foundation seed (produced from breeder seed with certified protocols).
- ✓ Purchase seeds only from authorized agencies, certified seed producers, or government outlets.
- ✓ Ensure the seed lot has:
  - Germination ≥ 85%
  - Physical purity ≥ 98%
  - Moisture content ≤ 9%
- ✓ Keep purchase records for seed certification purposes.

Sowing Practices

Proper sowing ensures uniform crop stand and maximum seed yield.

Seed rate: 15-20 kg ha^{-1} depending on seed size and germination percentage.

Spacing: Maintain 30-45 cm row spacing and 10 cm plant spacing within rows for adequate sunlight penetration and air circulation.

Sowing depth: 3-5 cm deep to ensure proper emergence.

Seed treatment

Fungicide: Treat seeds with Carbendazim or Thiram @ 2 g kg^{-1} seed to prevent seed-borne diseases.

Biofertilizers: Inoculate with *Rhizobium* culture to enhance nitrogen fixation and improve soil fertility.

Sowing time: Follow local agro-climatic recommendations (e.g., June-July for *Kharif*, February-March for summer crop) to avoid peak pest/disease pressure.

Field Inspections

Field inspections maintain genetic purity and identify early signs of disease or pest attacks.

Inspection stages

Pre-flowering stage: Identify and remove off-type plants (different leaf shape, color, growth habit).

Flowering stage: Look for diseased plants, especially those with YMV symptoms (yellow leaves, stunted growth).

Maturity stage: Check for uniform pod maturity and seed color.

Inspections should be conducted by both the producer and the seed certification agency (if applicable).

Roguing

Roguing is the physical removal of undesirable plants to maintain varietal purity.

Timing: Must be done before flowering to prevent cross-pollination.

What to remove

- ✓ Off-types with different leaf shape, plant height, or branching pattern.
- ✓ Plants showing symptoms of YMV, Cercospora leaf spot, or other diseases.
- ✓ Volunteer plants from previous crops.
- ✓ Roguing should be done carefully and removed plants should be destroyed to prevent seed mixing.

Harvesting and Post-Harvest Handling

Proper harvesting and post-harvest operations are crucial to maintain seed quality.

Harvest timing: When 80-85% of pods have turned brown/black and seeds inside rattle when shaken.

- ✓ Delayed harvesting increases shattering losses.
- ✓ Early harvesting may result in immature seeds with poor storage life.

Harvesting method: Manual harvesting with sickles or careful uprooting to minimize seed damage.

Threshing

- ✓ Use stick beating or mechanical threshers with low drum speed.
- ✓ Avoid over-threshing to prevent seed coat damage.

Drying: Reduce moisture content to 8-9% by sun-drying on clean tarpaulin or cemented floors.

Cleaning and grading: Use seed graders to remove inert matter, weed seeds, and undersized grains.

Seed treatment: Treat with insecticide (e.g., Malathion dust) before storage to prevent bruchid (*Callosobruchus maculatus*) infestation.

Storage: Store in moisture-proof bags (HDPE or metal bins) in a cool, dry, and pest-free place until marketing or sowing.

Seed Processing and Storage

Once the crop is harvested and threshed, the seeds must be processed to maintain their quality until the next sowing season.

Cleaning: Remove inert matter such as stones, dust, broken seeds, and plant debris. This improves physical purity and reduces pest hiding places.

Grading: Separate seeds based on size and weight using seed graders. Larger, uniform seeds have better germination and vigor.

Seed Treatment

Fungicide treatment: Apply Carbendazim or Thiram @ 2 g kg^{-1} seed to protect against seed-borne diseases.

Insecticide treatment: Use Malathion dust or other recommended chemicals to prevent storage pest infestation, especially bruchids (*Callosobruchus maculatus*).

Storage

- ✓ Store seeds in moisture-proof containers (HDPE

bags, polylined gunny bags, or metal bins).

- ✓ Keep in a cool, dry, and well-ventilated room away from direct sunlight.
- ✓ Maintain seed moisture at 8-9% for safe storage and high germination.
- ✓ Inspect stored seed periodically for insect or mold attack.

Seed Certification

Seed certification ensures the seed meets prescribed quality standards before it reaches farmers.

Certification agency role: State Seed Certification Agencies (SSCA) and other authorized bodies conduct inspections and laboratory tests.

Inspection stages: Pre-sowing, flowering, pod formation, and pre-harvest to ensure genetic purity and disease-free plants.

Laboratory testing

- ✓ Germination test (should be ≥ 85%).
- ✓ Physical purity (≥ 98%).
- ✓ Moisture content (≤ 9%).

Tagging: Once certified, seeds are labeled with a certification tag stating variety name, germination percentage, purity, and lot number.

Challenges in Mungbean Seed Production

- ✓ Susceptibility to Yellow Mosaic Virus (YMV) and Cercospora leaf spot, which can cause severe yield losses.
- ✓ Seed shattering at maturity, leading to 10-15% yield loss if harvesting is delayed.
- ✓ Storage pests, particularly bruchids, which damage seeds during storage.
- ✓ Limited access to quality seed in remote rural areas, forcing farmers to use low-quality, farm-saved seed.

Strategies to Overcome Challenges

- ✓ Use disease-resistant varieties such as Pusa Vishal, SML 668, and IPM 02-3 to minimize YMV losses.
- ✓ Harvest on time to prevent shattering and maintain seed quality.
- ✓ Adopt hermetic storage technologies like PICS bags or airtight metal bins to control bruchid infestation without chemicals.
- ✓ Develop seed villages to produce and supply quality seed locally, reducing farmers' dependency on distant markets.

Conclusion

Quality seed production in mungbean is one of the most cost-effective and sustainable ways to boost yield, improve farmers' income, and strengthen food security. By following scientific seed production protocols from variety selection and field management to proper storage farmers can ensure high germination, varietal purity, and better market value. Investments in farmer training, seed certification systems, and local seed production infrastructure will help build a strong, reliable mungbean seed supply chain across India.

Growing of Vegetables in Protected Environment under Changing Climate

Partha Saha, Namita Das Saha and Sulochana K. H.

Vegetables are rich sources of various health promoting substances and form an integral part of daily diet. Realizing the importance on human health, there is tremendous shift in vegetable consumption in India during the last few decades. India ranks second in vegetable crops production in the world. However, the production can't fulfill the requirement if balanced diet is to be provided. India occupies an area under protected cultivation is 2.0 lakh ha. Our total vegetable requirement is expected to 450 million tonnes by 2050. To achieve this target, protected cultivation can play a vital role. There are different ways and means to achieve this target, *e.g.*, bringing additional area under vegetable crops, using hybrid seeds, use of improved agro-techniques and growing off season vegetable crops. To meet the need of ongoing demand, the growing of vegetables under protected environment is the need of the hour. A great diversity of climatic condition exists in protected environment. In each location, environment varied enormously during the entire growing season and changes can occur very rapidly. Certain factors, in climate change scenario, *i.e.*, high rainfall, temperature stress, drought, salt, shortage of irrigation facilities, are responsible for low yield. Therefore, it is necessary to breed a variety which have wide adaptation to different climatic conditions. The choice of crops and development of cultivars for protected cultivation is a fundamental variable that may significantly affect the success and economic return of the entire production process.

Challenges

Almost all the varieties/hybrids developed in vegetable crops were breed for open field cultivation and are not suitable for protected environment due to their low yield, poor quality and low profit under protected cultivation. Therefore, breeding of suitable indigenous varieties or hybrids in vegetables is an urgent research priority for proper development and expansion of the protected growing area in the country. There are always problems of nematodes and other soil borne diseases in protected structure due to growing of same crop year after year under protected structure. Therefore, the variety should have resistance to these stresses.

Strategies for research for growing vegetables under protected environment

Selection of crops: High value low volume crops like tomato, capsicum, cucumber, muskmelon and gherkin are suitable for growing under protected environment. The other high-priced vegetables like cherry tomato, bitter gourd, muskmelon and summer

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squash which have demand in big cities are suitable for protected cultivation.

Development of suitable varieties: In the protected environment, the vertical space is mostly utilized, so the plant type should be indeterminate in nature. The crops undergo extreme low and high temperatures during different growth stages; the genotype should tolerate low and high temperature stress. Limited breeding work has been taken up for development of suitable varieties/hybrids for protected environment in India. Mostly the imported varieties are grown in protected cultivation. These seeds are very costly and are out of reach of the Indian growers. Therefore, emphasis have been given to develop indigenous F_1 varieties/hybrids suitable for protected environment so that seeds are available to the growers at cheaper rates.

In tomato indeterminate growth habit with continuously single stemmed flowers and fruits along the main stem are suitable for protected cultivation. These varieties reach to a length of 20-30 ft in 10-months and can grow over a long period of time.

In cherry tomato, the variety should be indeterminate, with dark green foliage, round, medium sized, sweet, deep red or yellow with good shelf life.

Capsicum or sweet pepper has great prospect in protected environment. This crop is gaining popularity among small and marginal farmers with the availability of indigenous varieties. The plants should be erect with short internode and wider canopy. The fruits should be cylindrical shape with different coloured types (green, red, yellow, orange). Early and late flowering with prolonged harvesting span, parthenocarpy, high yield potential, thermo and photo insensitivity and sturdy plants with indeterminate growth habit are important traits for protected environment.

Cucumber is another crop which is greatly weather sensitive and suitable to grow under protected condition. Plants having indeterminate growth habit with constant internode length are suitable to grow under protected environment. Parthenocarpic gynoecious cucumbers are very much suitable as these varieties develop fruits without pollination. Therefore, emphasis should be given to develop parthenocarpic gynoecious hybrids. Besides, fruits should be attractive green in colour, cylindrical shape, smaller seed locules, tender skin, sweet in taste (cucurbitacin free) and crispy.

The vegetable varieties suitable for growing under protected environment are given in Table 1.

Development of suitable production practices

Further, work on crops-specific fertigation, pollination management, training pruning are also standardized for crops like capsicum, cucumber, tomatoes. Standardizing proper designing of low-medium cost protected structure including cladding and glazing material is required.

In protected cultivation, fruit thinning is done for proper development of fruits. In some cases, self-pruned variety saves the labours.

Table 1: List of vegetable varieties suitable for growing under protected cultivation

Crop	Varieties
Tomato	Pusa Tomato (Protected-1), Pusa Rakshit, Arka Meghali, Arka Saurav, Pant Polyhouse Tomato-1, Pant Polyhouse Tomato hybrid-1
Cherry tomato	Pusa Cherry Tomato-1, Pusa Golden Cherry Tomato-2, Punjab Red Cherry, Punjab Sona Cherry, Punjab Kesar Cherry
Capsicum	Arka Gaurav, Arka Basant, VL Shimla Mirch 3
Cucumber	Pusa Parthenocarpic Cucumber-6, Pant Parthenocarpic Cucumber-2 and 3, Palam Khira-1, KAU Parthenocarpic Cucumber Hybrid-1
Bitter gourd	Pusa Rasdar, Hybrid DARL 102
Musk melon	Pusa Sarda
Bottle gourd	DARL-25

Conclusion

Growing vegetables under protected environment is still in its preliminary stage in India and concerted efforts are required from all concerned agencies to bring it at par with the global standards. Economically viable technology suitable for the Indian agro-climatic and geographical conditions is needed at the earliest. Besides, creation of awareness among farmers pertaining to the potential of protected vegetable production is needed for successful protected cultivation in India.

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Source-Sink Relationship and Modulation of Photosynthesis in Plants: A Review

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Abstract

The source-sink relationship is a central concept in plant physiology that governs the production, transport, and utilization of assimilates. Source organs, primarily mature photosynthetic leaves, produce carbohydrates, while sink organs such as roots, developing fruits, and young tissues demand these assimilates for growth and storage. The balance between source activity and sink strength plays a critical role in determining the rate of photosynthesis, biomass accumulation, and ultimately crop yield. Modulation of photosynthesis by the source-sink relationship occurs through feedback mechanisms involving carbohydrate signaling pathways. An imbalance between source capacity and sink demand often leads to downregulation of photosynthetic efficiency, while enhanced sink strength can stimulate sustained photosynthetic activity. Understanding these interactions provides valuable insights for improving crop productivity through agronomic management and genetic improvement.

Introduction

The growth, development, and yield potential of plants depend on the efficient coordination between carbon assimilation, transport, and utilization processes (Paul and Foyer, 2001). Photosynthesis, the primary mechanism for converting light energy into chemical energy, occurs predominantly in mature leaves, which function as source organs (Taiz *et al.*, 2015). These source organs produce carbohydrates, mainly in the form of sucrose, which are translocated to non-photosynthetic sink organs that require energy and structural components for growth (Patrick, 1997). Sink organs include roots, young leaves, flowers, developing fruits, and seeds, all of which depend on imported assimilates to support their metabolic and developmental processes (Lemoine *et al.*, 2013). The source-sink relationship describes the physiological and biochemical connection between carbon-producing and carbon-consuming tissues, forming the basis for whole-plant growth and biomass partitioning (Marcelis, 1996). Conversely, strong sink demand, such as during active fruit development or root growth, enhances the export of assimilates, prevents feedback inhibition, and stimulates continued photosynthetic efficiency (Sonnewald and

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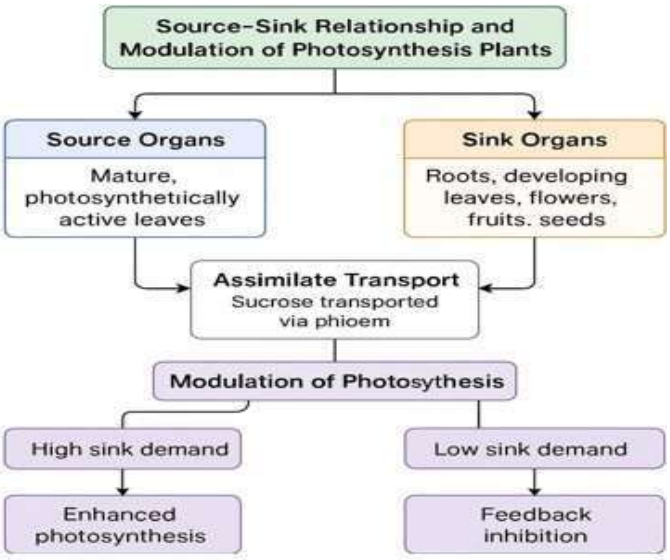
Fernie, 2018). Understanding the mechanisms governing the source-sink relationship is essential for optimizing plant productivity, especially in the context of increasing global food demand and climate change challenges (Taiz *et al.*, 2015). Research into improving source-sink coordination through agronomic practices and genetic approaches holds significant potential for enhancing crop yield and resource use efficiency (Slafer and Savin, 1994).

Concept of Source and Sink Organs: In higher plants, source organs refer to mature leaves capable of producing carbohydrates via photosynthesis (Lemoine *et al.*, 2013). Conversely, sink organs include developing leaves, roots, flowers, fruits, and seeds that consume or store these carbohydrates for growth and development (Patrick, 1997). The primary assimilate transported from source to sink is sucrose, which moves through the phloem via active loading mechanisms (Turgeon, 2010). The source-sink balance is highly dynamic, shifting with developmental stages, environmental factors, and internal metabolic cues (Farrar and Jones, 2000).



Modulation of Photosynthesis by Source-Sink Balance: Photosynthesis is a highly regulated process controlled by both environmental signals and internal metabolic demands (Paul and Pellny, 2003). While external factors such as light, CO_2 concentration, water availability, and temperature directly influence photosynthetic rates, internal source-sink dynamics play an equally critical role in modulating this process (Taiz *et al.*, 2015). Source leaves, particularly mature, photosynthetically active organs, generate assimilates like sucrose that are transported to sink organs through the phloem (Lemoine *et al.*, 2013). When the sink demand for assimilates is high, such as during active fruit or seed development, the continuous export of sugars from source leaves maintains photosynthetic efficiency and prevents feedback inhibition (Sonnewald and Fernie, 2018).

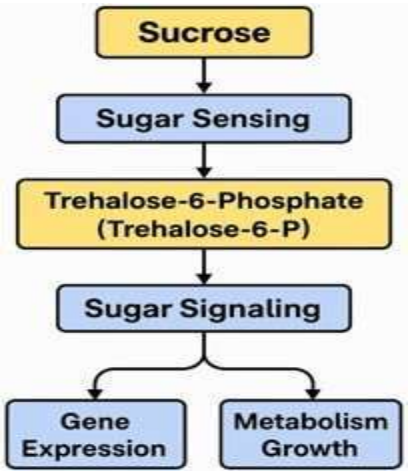
In contrast, when sink demand is low due to developmental arrest, stress conditions, or insufficient sink capacity, carbohydrates accumulate within source leaves (Patrick, 1997). This accumulation of sugars, especially sucrose and hexoses, triggers feedback regulation that inhibits photosynthetic gene expression and reduces photosynthetic enzyme activity (Goldschmidt and Huber, 1992). Therefore, maintaining an optimal source-sink relationship is essential to maximize photosynthetic efficiency, especially in crop plants where yield is closely tied to carbon assimilation and partitioning (Sonnewald and Fernie, 2018). Future research aimed at improving sink strength through

genetic engineering, breeding, and agronomic practices holds promise for enhancing photosynthetic rates and overall plant productivity (Lemoine *et al*., 2013).

Mechanisms of Photosynthetic Modulation

Carbohydrate Accumulation and Feedback Inhibition: Excess sugar accumulation in source leaves can suppress photosynthetic gene expression and reduce photosynthetic enzyme activity (Goldschmidt and Huber, 1992).

Sugar Signaling Pathways: Sugars like glucose and sucrose function as signaling molecules that regulate gene networks involved in photosynthesis and growth (Rolland *et al*., 2006).

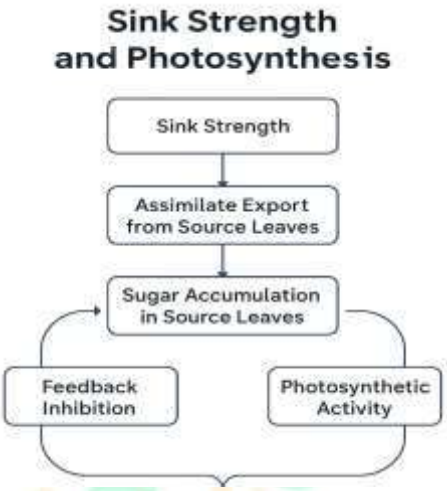


Sink Strength and Photosynthesis: Sink strength refers to the capacity of plant sink organs to import, store, or metabolize assimilates such as sucrose and other carbohydrates (Ho, 1988). It is determined by two main factors: the size of the sink (sink size) and the metabolic activity or demand of the sink (sink activity) (Marcelis, 1996). Sink organs, including roots, developing leaves, flowers, fruits, seeds, and storage structures like tubers or bulbs, rely on the continuous supply of photoassimilates from source leaves (Patrick, 1997). The relationship between sink strength and photosynthesis is tightly linked through feedback regulatory mechanisms (Paul and Foyer, 2001). When sink strength is high, assimilates produced by photosynthesis are rapidly exported from source leaves to sink organs, maintaining low sugar concentrations in source tissues (Sonnewald and Fernie, 2018). This facilitates sustained photosynthetic activity, as low sugar accumulation prevents feedback inhibition of photosynthetic enzymes and gene expression (Goldschmidt and Huber, 1992). However, when sink strength is insufficient due to developmental stages, environmental stress, or limited sink organ growth carbohydrates accumulate in source leaves (Paul and Pellny, 2003). Excess sucrose and starch in source leaves trigger feedback inhibition, leading to a decline in Rubisco activity, chlorophyll biosynthesis, and photosynthetic gene expression (Rolland *et al.*, 2006). Thus, sink strength acts as a major determinant of the photosynthetic rate by regulating carbohydrate turnover and export from source tissues

(Lemoine *et al*., 2013). Experimental studies have demonstrated that artificially increasing sink strength can improve photosynthetic performance (Marcelis, 1996). For example, increasing fruit number or biomass in tomato plants enhances sink demand, promoting sugar export from leaves and stimulating higher rates of photosynthesis (Ho, 1988). Similarly, enhancing root growth in crops such as wheat or maize increases sink capacity, facilitating greater carbon allocation and sustained photosynthetic activity (Slafer and Savin, 1994).

Conversely, removal of sink organs (e.g., fruit thinning or root pruning) reduces sink strength, leading to carbohydrate accumulation in leaves and decreased photosynthesis (Goldschmidt and Huber, 1992). Genetic studies have also shown that crop varieties with larger sink organs, such as seeds or tubers, maintain higher photosynthetic rates due to greater sink demand (Sonnewald and Fernie, 2018). Hormonal signals, including auxins, cytokinins, and gibberellins, influence sink strength by regulating sink organ growth and metabolic activity (Taiz *et al*., 2015). Additionally, sugar signaling molecules like trehalose-6-phosphate (T6P) integrate carbohydrate status with sink activity, coordinating source-sink balance (Figueroa and Lunn, 2016).

The concept of sink strength is particularly important in agricultural systems where maximizing yield depends on effective source-sink coordination (Paul and Foyer, 2001). Breeding for crops with improved sink strength, through larger fruits, seeds, or storage tissues, offers a promising strategy to enhance photosynthetic efficiency and productivity (Lemoine *et al*., 2013). Therefore, sink strength plays a pivotal role in modulating photosynthesis by dictating carbohydrate export, preventing feedback inhibition, and maintaining optimal source-sink relationships (Sonnewald and Fernie, 2018).



Agricultural and Physiological Significance: Understanding source-sink dynamics is crucial for crop improvement strategies aimed at enhancing yield (White *et al*., 2016). Practices like pruning, fertilization, and genetic modification of sink capacity can optimize photosynthesis (Sonnewald and Fernie, 2018). Breeding for increased sink strength (e.g., larger grains or fruits) ensures sustained photosynthetic activity and improved biomass accumulation (Slafer and Savin, 1994).

Conclusion

The source-sink relationship is a central physiological mechanism that governs plant growth, development, and overall productivity (Patrick, 1997). Efficient coordination between photo-synthetic source organs and assimilate-demanding sink organs ensures optimal carbon assimilation,

transport, and utilization (Paul and Foyer, 2001). Photosynthesis in source leaves is not an isolated process but is tightly regulated by sink demand through feedback mechanisms (Goldschmidt and Huber, 1992).

When sink strength is adequate, continuous export of carbohydrates from source leaves prevents sugar accumulation, allowing sustained photosynthetic activity (Sonnewald and Fernie, 2018). Conversely, limited sink strength leads to excess carbohydrate accumulation in source tissues, triggering feedback inhibition of photosynthesis at both biochemical and gene expression levels (Paul and Pellny, 2003). This feedback regulation ensures metabolic balance but can also limit biomass production and yield if sink demand is not optimized (Lemoine *et al.*, 2013). Understanding the modulation of photosynthesis through source-sink dynamics has significant implications for agriculture (Ho, 1988).

Enhancing sink strength by breeding for larger fruits, seeds, storage tissues, or through agronomic practices such as pruning and thinning can improve photosynthetic efficiency and crop yields (Marcelis, 1996). Moreover, integrating sugar signaling pathways, particularly the role of trehalose-6-phosphate (T6P), offers new opportunities to manipulate source-sink relationships for enhanced productivity (Figueroa and Lunn, 2016). Environmental factors such as light, temperature, water availability, and nutrient status significantly influence source-sink coordination, photosynthesis, and yield formation (White *et al*., 2016). Thus, adopting management strategies that support both source activity and sink development is essential for improving plant resilience and performance under variable environmental conditions (Chaves *et al*., 2003). In conclusion, optimizing source-sink relationships through genetic, physiological, and agronomic approaches is a promising strategy to enhance photosynthesis, crop productivity, and sustainability in agricultural systems (Sonnewald and Fernie, 2018).

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From Participation to Leadership: Gender Mainstreaming Tools and Practices in Watershed Management

Kaustubh Kadam, Pooja Limbhore and Anjali Dahatonde

Introduction

Watershed management stands at the heart of rural transformation in India, threading together the livelihoods of millions, food security, natural resource conservation, and community resilience. Yet, the invisible threads that hold this fabric strong are often spun by women whose contribution, leadership, and unique challenges have long gone underrecognized. Imagine an India where women, who constitute nearly half the rural workforce, have equal control over land, water, and agricultural resources a place where their knowledge and participation shape sustainable futures for their families and environment. This, however, remains more vision than reality.

Gender and Agriculture: The Indian Picture

Women's participation in Indian agriculture is both vast and critical yet deeply undervalued and inequitable. Their engagement ranges from manual labor to resource management and decision-making, but disparities in access, recognition, and returns continue to undermine their potential.

Women are decision-makers, cultivators, water managers, and food security champions, but typically lack equitable access to extension services, credit, markets, and land. Worse, the feminization of agriculture driven by male migration has increased women's responsibilities without concurrent empowerment or reduction in drudgery.

Key Statistics on Women in Indian Agriculture and Watershed Context

Sr.No	Indicator/Area	Statistic
1.	Women in Indian agricultural workforce	65%* (2011 Census)
2.	Participation in agricultural activities	52% (Paddy, max.), 40.5% (Wheat systems)
3.	Share in forest produce collection (NTFPs)	Tribal women: Fuelwood (60%), Salia (12%)
4.	Female literacy rate (India, 2011)	65.46% (vs. 82.14% male)
5.	Gender wage gap in rural casual labor	30-50% less than men
6.	Women's access to land	<13% landownership among rural women
7.	Share of women among SHG members	Rising rapidly, but sustainability is key

Source (ICAR-Central Institute for Women in Agriculture)

*Down from 71.8% (2001) due to mechanization and migration

Gender mainstreaming in integrated water-shed management is a transformative approach aimed at ensuring equitable participation, decision-making, and benefit-sharing among men and women throughout the planning, implementation, and evaluation of watershed development initiatives. In India, where women are significant contributors to agriculture and allied sectors, their roles and needs have historically been overlooked in the conception and execution of natural resource management projects. As highlighted in the compendium cum training module developed for the Odisha Watershed

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Development Mission, mainstreaming gender is critical not only for social justice but also for enhancing the effectiveness and sustainability of watershed programmes. Gender mainstreaming refers to the systematic consideration of gender perspectives, needs, roles, and constraints in all stages of policy, project design, implementation, and evaluation. It is not mere inclusion, but a deliberate push for equity ensuring women and men benefit equally, and ending gender-blind development failures.

Understanding Gender Issues in Watershed Management

Watershed projects are uniquely positioned to advance gender equality, given their reliance on community resource management, labor-sharing, and decision-making. Yet, persistent barriers abound:

Limited Participation in Governance: Women rarely participate in planning, execution, or monitoring of watershed programmes, due to mobility constraints, social norms, or lack of recognition.

Access and Control Gaps: Customary structures often hinder women's access to land, credit, technology, and benefits from common property resources (CPRs).

Drudgery and Health Risks: Women undertake most labor-intensive and hazardous tasks fetching water, transplanting, weeding, postharvest processing yet benefit least when interventions increase productivity.

Inequitable Benefit Sharing: New assets or income opportunities often accrue to those controlling land or community bodies, frequently excluding women, the landless, and marginalized groups.

Social and Cultural Dynamics

Gender roles are forged by both necessity and tradition. In watershed contexts:

- ✓ Women manage water for agriculture, livestock, and domestic use, making them repositories of indigenous resource knowledge.
- ✓ Despite triple roles (production, reproduction, community management), women's contributions remain invisible in planning and benefit-sharing.
- ✓ Mobility, decision power, and access to training are often restricted for women across regions, especially among marginalized communities.

Why Focus on Gender in Watershed Interventions?

Evidence shows

Productivity & Food Security: If women had the same access to productive resources as men, agricultural yields could rise by 20-30%, reducing hunger by 12-17% globally.

Sustainability: Women's resource management and indigenous knowledge enhance sustainable use of land, water, forests, and biodiversity.

Social Equity: Inclusive watershed projects can reshape power relations, boost girls' education, reduce health risks, and foster community resilience.

Tools and Strategies for Gender Mainstreaming

The multiple methodologies and practical

tools for field-level gender analysis and action planning:

Gender Analysis Tools

- ✓ Harvard Analytical Framework
- ✓ Gender Analysis Matrix
- ✓ Longwe's Empowerment Framework
- ✓ People-Oriented Planning (POP)
- ✓ Social Relations and SEAGA Frameworks

Participatory methods include

- ✓ Village resource and social mapping
- ✓ Trend lines, pairwise ranking, Venn diagrams
- ✓ Farming system diagrams, daily activity clocks
- ✓ Seasonal calendars, benefit analysis flowcharts
- ✓ Stakeholder analysis and conflict matrices

These tools help identify women's roles, workload distribution, access to/control over assets, local priorities, and intra-household decision-making, forming the basis for equitable project design.

Gender-Responsive Planning and Implementation

Key steps involve ensuring:

- ✓ Women's representation in Watershed Management Committees.
- ✓ Gender-sensitive timing and locations for meetings and training.
- ✓ Gender-disaggregated data collection for diagnosis and monitoring.
- ✓ Encouragement of women's leadership development and voice in group decisions.
- ✓ Adjustments of project objectives, execution, and benefit-sharing to women's needs and feedback.

Best Practices

- ✓ Integrate gender equity from project inception through evaluation.
- ✓ Promote women-friendly technologies (e.g., improved hand tools, safe water access, reduced drudgery implements).
- ✓ Facilitate access to credit, market linkages, and extension services for women SHGs.
- ✓ Organize capacity-building workshops on rights, leadership, and technical skills.

Gender-Sensitive Technologies & Interventions

Livestock: Women lead in backyard poultry, goat and sheep rearing, dairy; interventions must align with existing roles and improve access to veterinary services, new breeds, feed, markets.

Horticulture: Women excel in nursery raising, protected cultivation (polyhouses), floriculture, mushroom cultivation, seed production, and value addition. Tailored training, microfinance, and market access boost impact.

Fisheries: Women's involvement expands from subsistence to small-scale aquaculture, integrated fish farming, seed production, and postharvest fish processing with adequate support, access, and technology.

Women-Friendly Innovations

- ✓ Use of ergonomic hand tools.
- ✓ Small-scale food processing enterprises.
- ✓ Integrated Pest Management (IPM) and botanical pesticides to reduce chemical exposure.
- ✓ Access to renewable energy (for food preservation, water lifting).

Drudgery Reduction and Health Hazards

Agriculture exposes women to repetitive stress, hazardous chemicals, poor nutrition, and occupational injury. Responses include:

- ✓ Introduction of ergonomically designed tools.
- ✓ Targeted drudgery-reducing equipment.
- ✓ Awareness and training on occupational health and safety.
- ✓ Increasing availability of personal protective equipment, proper maintenance, and health monitoring.

Women's Collective Entrepreneurship: SHGs

Self-Help Groups (SHGs) are recognized as vehicles for economic and social empowerment, particularly for landless and marginalized women. However, sustainability and impact require:

- ✓ Strong market linkages and business mentorship.
- ✓ Access to microcredit, value-addition training, and risk-sharing.
- ✓ Model variations: direct Producer-Trader linkages, local entrepreneurship hubs, community networks for product diversification and marketing.

Policy Architecture and Programmes for Women Empowerment

A supportive policy ecosystem is essential for mainstreaming gender:

Constitutional Guarantees: Articles 14, 15, 16, 39, and 42 ensure equality and affirmative state action for women.

National Policy for Women Empowerment (2001): Advocates full participation, gender-sensitive planning, legal equality, and social security.

Women Component Plan (WCP): Mandates 30% allocation of development funds to women-centric schemes.

National Nutrition/Health/Education Policies: Address underlying determinants of rural women's vulnerability.

National Mission for Empowerment of Women, Mahila Shakti Kendra, and related Missions: Coordinate convergence and implementation at multiple levels.

Social Security and Legal Frameworks

Watershed women beneficiaries can leverage entitlements from a broad array of social security and empowerment schemes:

- ✓ Swayamsidha, RGSEAG, Swadhar, Ujjawala, Working Women's Hostels, Mission Shakti, Mahila Mandal, SHGs, STEP, Rashtriya Mahila Kosh, and old-age/disability pension schemes.
- ✓ Protection from domestic violence, property rights, representation in Panchayats and community institutions, anti-trafficking laws.
- ✓ Support for schooling, nutrition, and health of girls through conditional cash transfers, special hostels, creches.

Conclusion

Gender mainstreaming in integrated watershed management is not only a matter of justice or parity it is a strategic necessity for ecological sustainability, agricultural productivity, rural prosperity, and community resilience. Ignoring the needs, knowledge, and leadership of half the rural

population undermines the effectiveness and sustainability of watershed interventions. The ICAR-CIWA's compendium provides a robust toolkit and roadmap for moving beyond tokenism, integrating women's voices into every stage of watershed planning and implementation. It calls for a concerted effort among policymakers, field officers, researchers, SHGs, and local communities to recognize, quantify, and build upon women's centrality to rural transformation.

The Way Forward: Transforming Indian Extension for Gender-Responsive Watershed Management

Institutionalizing Gender Analysis: Every extension activity, from needs assessment to technology dissemination, should explicitly analyze and address gender roles, constraints, and opportunities. All field staff need practical training in gender-sensitive methodologies and monitoring.

Enhancing Women's Capacity and Leadership: Extension services must prioritize the empowerment of women farmers and farm entrepreneurs by organizing regular, accessible, and targeted trainings. This includes functional literacy, business skills, technical skills, and leadership training to enable active participation in community resource management.

Expanding Women-Friendly Technologies: Research and extension systems must invest in developing, scaling, and maintaining women-friendly agricultural tools and technologies that reduce drudgery and enhance productivity especially in pre- and post-harvest activities, irrigation, and livestock management.

Facilitating Market and Value Chain Access: India must move beyond demonstration-based extension to supporting sustainable women's enterprises, with robust linkages to input/output markets, financial services, and business mentorship.

Mainstreaming Social Security and Rights: Watershed projects should be a gateway for women to access broader social security benefits, health information, legal awareness, and entitlements through single-window systems, convergence with social sector departments, and capacity-building in legal literacy.

Inclusive, Participatory Planning: Project design, monitoring, evaluation, and outcome tracking must be truly participatory and gender-responsive, with women's groups centrally involved in decision-making, grievance redressal, and feedback mechanisms.

Gender-Sensitive Extension Policy: Gender budget-ing and commitment at every level national, state, Panchayat, and project must be embedded as policy. Extension institutions should reward and recognize gender equity outcomes.

Cultivating a New Generation of Change Agents: Critical to change is a cadre of gender-sensitized extension functionaries, local champions, and SHG leaders, continuously supported and incentivized to advance women's voices and agency.

Broccoli Cultivation in India: Recent Advances and Future Prospects

Ayusha Gupta and Pragati

Abstract

Broccoli, a vegetable packed with nutrients, is becoming increasingly popular in India. Once viewed as an exotic option, it is now seen as a valuable crop in many states, thanks to its well-known health benefits and growing consumer interest. Recent advancements in breeding have introduced high-yielding and heat-resistant hybrids, allowing farmers to grow broccoli in areas where it wasn't traditionally cultivated. Innovative farming methods like protected cultivation, organic farming, hydroponics, and vertical farming are also boosting production. Moreover, practices such as integrated nutrient and pest management, along with better post-harvest techniques, are helping improve both productivity and market appeal. Adding value through products like frozen florets, powders, and health supplements, along with chances to export to Gulf and Southeast Asian countries, enhances its economic prospects. Looking ahead, there are promising opportunities in researching climate-resistant varieties, building stronger cold chains, and empowering farmers with better skills. It's clear that broccoli is on track to become one of India's top high-value vegetables.

Introduction

Broccoli (*Brassica oleracea var. italica*) belongs to cole crop family, known for its impressive nutritional profile. Part of the Brassicaceae family, it's closely related to cabbage and cauliflower, but broccoli has its own unique charm with its tender green florets that we enjoy as a vegetable. Even though broccoli isn't a traditional staple in Indian cuisine like cauliflower, it's quickly becoming a favorite. Its rich nutritional benefits and health-boosting properties have caught the attention of many. Once considered an 'exotic' vegetable primarily found in urban markets, broccoli is now gaining ground in India as a crop of growing economic importance. Farmers in regions such as Punjab, Haryana, Himachal Pradesh, Uttarakhand, Maharashtra, and Karnataka are now cultivating it on a commercial scale. With its attractive market price, increasing demand among health-conscious buyers, and adaptability for both open-field and protected farming, broccoli is emerging as a promising vegetable crop in India.

Origin, Distribution, and Global Status: Broccoli has roots in the Mediterranean, especially in Italy, where it was cultivated from wild cabbage many centuries ago. It made its way across Europe in the

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16th century and eventually reached North America and Asia. Today, broccoli and cauliflower together contribute to over 25 million tonnes of production worldwide each year. China is the top producer, both in terms of area and volume, followed closely by India, which has become the second-largest producer.

Nutritional and Health Importance: Broccoli stands out as one of the vegetables packed with essential nutrients. It holds impressive levels of vitamin C, offering about 89 mg for every 100 grams, along with significant amounts of vitamin K, folate, and dietary fiber. Additionally, this green powerhouse provides important minerals like potassium, calcium, iron, and phosphorus. What truly sets broccoli apart are its bioactive compounds, such as glucosinolates and sulforaphane.

Table 1: Nutritional comparison of broccoli and cauliflower (per 100 g fresh weight)

Nutrient	Broccoli	Cauliflower
Energy (kcal)	34	25
Protein (g)	2.8	1.9
Vitamin C (mg)	89.2	48.2
Vitamin K (µg)	101.6	15.5
Folate (µg)	63	57
Calcium (mg)	47	22

(Source: USDA, ICAR-IIVR Varanasi, 2024)

Current Status of Broccoli Cultivation in India

Broccoli introduce in India only in the late 20th century, but since then, it has progressively gained popularity. The National Horticulture Board (2023) reports that broccoli is now grown across an estimated area of 20,000 to 25,000 hectares, yielding around 80,000 to 100,000 tonnes each year are given in Table 2.

Improved Varieties and Hybrids: The development of new broccoli varieties has played a key role in boosting its cultivation across India (Table 3).

Agronomic Practices

Climate and Soil: Broccoli flourishes in cool, moist environments, ideally thriving at temperatures between 15 and 20 °C. When temperatures stray too far from this range, the plant can suffer from issues such as loose heads or premature bolting. For optimal growth, well-drained loamy soils that are rich in organic matter and have a pH level between 5.5 and 6.5 are recommended.

Nursery and Transplanting: In terms of propagation, seeds are typically sown in raised beds, and the seedlings will be ready for transplanting in about 25 to 30 days. The best time for sowing seed in nursery is mid-August to mid-September. A seed rate of around 400 to 500 grams per hectare is advised. When transplanting, spacing should be adjusted to either 45 × 45 cm or 60 × 45 cm, depending on the specific variety.

Fertilization: Fertilization is an important step, with the application of 20 to 25 tonnes of farmyard manure along with 120 to 150 kg of nitrogen, 60 kg of phosphorus, and 60 kg of potassium per hectare being standard practice. Nitrogen is often applied in three separate doses. Additionally, incorporating micronutrients like boron and molybdenum is vital to prevent potential disorders.

Irrigation: As for irrigation, it's crucial to water the plants every 7 to 10 days, particularly during the initial stages of curd formation and growth. Utilizing drip irrigation combined with mulching can signific-

Table 2: Broccoli production in major Indian states

State	Main Districts	Season	Characteristics of Production
Himachal Pradesh	Solan, Shimla, Mandi	Summer	Off-season supply for plains
Punjab	Ludhiana, Jalandhar	Winter	Commercial farming for markets
Haryana	Karnal, Panipat	Winter	Expanding acreage near Delhi
Maharashtra	Pune, Nashik, Satara	Winter	Linked to supermarkets, export
Karnataka	Bengaluru, Kolar	Winter	High demand in metro cities
Uttarakhand	Dehradun, Almora, Nainital	Summer	Mid-hill cultivation

Table 3: Improved varieties and hybrids of broccoli in India

Variety/Hybrid	Source/Institute	Days to Maturity	Yield (q ha^{-1})	Superior Traits
Punjab Broccoli	PAU, Ludhiana	65-70	150-180	Compact, attractive heads
Palam Samridhi	YSPUHF, Solan	70-75	180-200	Suitable for hills, dome-shaped
Pusa KTS-1	IARI, New Delhi	90-105	200-220	Heat-tolerant, plains variety
Palam Vichitra	YSPUHF, Solan	80-85	200-225	Purple heads, high nutrients
Green Magic (F_1)	Syngenta	65-70	200-250	Uniform export quality
Fiesta (F_1)	Private sector	70-80	200+	Dome-shaped, firm curds

Table 4: Physiological Disorders and Management

Disorder	Cause	Management
Whiptail	Molybdenum deficiency	Foliar spray of ammonium molybdate (0.01%)
Browning	Boron deficiency	Apply borax @ 20 kg ha^{-1}
Hollow stem	High nitrogen and rapid growth	Balanced fertilization
Bolting	High temperatures	Timely sowing, use of tolerant varieties

Table 5: Major Insect-Pests and Diseases of Broccoli and their Management

Pest/Disease	Symptoms	Control Measures
Aphids (*Brevicoryne brassicae*)	Colonies on leaf underside, sap sucking causes yellowing, curling, weak plants	Spray Monocrotophos (0.05%) or Malathion (0.1%) at 10-15 day intervals; apply Phorate 1.0 kg a.i. ha^{-1} to soil
Cabbage Diamondback Moth (*Plutella xylostella*)	Caterpillars feed inner leaves, make transparent patches, skeletonize foliage	Neem formulations (4 ml l^{-1}), Bt (Delfin 3G @ 1 g l^{-1}); spray Malathion (0.1%) or Profenofos (0.25-0.5 kg a.i. ha^{-1})
Leaf Webber (*Crocidolomia binotalis*)	Caterpillars web leaves into bunches and feed inside; reduces photosynthesis and flowering	Remove and destroy webbed leaves; dust with Carbaryl (4%) or spray Malathion (0.05%)
Black Rot (*Xanthomonas campestris*)	V-shaped lesions from leaf margins, yellowing, black veins, small poor-quality heads	Seed treatment with Agrimycin-100/ Streptocycline (100 ppm); raised beds; crop rotation; rogue infected plants
Downy Mildew (*Peronospora parasitica*)	Yellow spots on upper surface, grey patches below, wilting under humidity	Destroy alternate hosts; spray Copper Oxychloride (0.3-0.5%); neem seed kernel extract (5 ml l^{-1}) after 25-30 days
Leaf Spot & Blight (*Alternaria brassicae, A.*	Dark circular spots with concentric rings and yellow halos; severe	Hot water seed treatment (50 °C, 30 min); spray Captan (0.2%) or Copper Oxychloride (0.5%) at bloom, pod set,

antly enhance water efficiency.

Plant Protection: Like many other cole crops, broccoli faces threats from various insect pests and diseases that can greatly impact both its yield and market quality.

Harvesting and Yield: Broccoli is ready to be harvested when its heads are compact, firm, and a rich dark green, just before the flower buds start to loosen or turn yellow. The time it takes to grow varies by type: early hybrids usually need around 60 to 70 days, while medium varieties require 80 to 90 days, and late-maturing kinds can take up to 90 to 110 days after they've been transplanted. Typically, harvesting is done by hand with a sharp knife, cutting the central head along with about 10 to 15 centimetres of stalk to keep it fresh. Interestingly,

after the main head is picked, some varieties will continue to grow smaller side shoots, which can be harvested later to prolong the harvesting season. On average, open-pollinated varieties yield roughly 100 to 150 quintals per hectare. In contrast, improved hybrids, when cultivated under optimal agronomic conditions, can produce between 150 to 250 quintals per hectare.

Post-Harvest Management: Broccoli is known to spoil quickly because of its high respiration rate. It's best to harvest it when the heads are tight and vibrant green. Under regular room conditions, broccoli only stays fresh for about 2 to 3 days. However, if you pre-cool it and keep it stored between 0 to 4 °C, you can extend its shelf life to 2 to 3 weeks. To add more value, modified atmosphere packaging and freezing methods are becoming more common.

Recent Advances in India

Protected Cultivation: The introduction of polyhouses, shade nets, and low tunnels has enabled farmers to grow broccoli even in the off-season. This not only guarantees a consistent supply but also allows them to fetch higher prices. Such methods are especially popular in the peri-urban areas surrounding Delhi, Pune, and Bengaluru, where supermarkets and hotels have a strong demand.

Organic Cultivation: In hill states like Himachal Pradesh, Uttarakhand, and Sikkim, organic broccoli farming is gaining popularity due to the favorable climate and growing consumer preference for chemical-free produce.

Hydroponics and Vertical Farming: Modern farming systems such as hydroponics and vertical farming are being adopted in and around metro cities. These methods ensure year-round production of high-quality broccoli using less land and water.

Value Addition Post-harvest processing is another area of advancement. Frozen florets, dehydrated broccoli powders, instant soup mixes, and nutraceutical products are increasingly being developed by food industries.

Export Potential: India is gradually emerging as a broccoli exporter, with growing demand in Gulf and Southeast Asian countries. States like Maharashtra and Karnataka are exploring broccoli export chains, supported by cold storage, packaging, and improved logistics.

Conclusion

Broccoli farming in India is still in its early stages, but it's growing quickly. This surge is driven by its health benefits and increasing popularity among consumers. Improvements in breeding techniques, farming methods, and ways to handle the crop after harvest are helping more farmers get on board. With the right policies, better facilities, and innovative research, broccoli could play a big role in boosting farmers' earnings and enhancing the nation's nutritional health.

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Green Solutions: The Role of Essential Oils in Crop Disease Management

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Abstract

Bacterial and fungal diseases in crops cause substantial economic losses, while reliance on synthetic agrochemicals raises ecological and health concerns. Plant-derived essential oils (EOs), which are natural secondary metabolites, offer a sustainable alternative due to their antimicrobial, insecticidal, and antioxidant properties. Their chemical makeup and biological activity are influenced by the plant source, extraction approach, and environmental factors, with newer techniques such as microwave-assisted and supercritical fluid extraction enhancing yield and efficiency. The antimicrobial action of EOs is largely linked to their ability to destabilize cell membranes, modify permeability, and interfere with vital metabolic pathways, making them effective against a range of plant pathogens. Practical applications include seed disinfection, soil biofumigation, and combination with beneficial microbes, demonstrating promise for integration into eco-friendly crop protection strategies. Nonetheless, issues such as limited stability, inconsistency in composition, and high production costs restrict large-scale agricultural use. Ongoing research and technological innovation are essential to improve the durability and field applicability of EOs in managing plant diseases.

Introduction

Crop diseases caused by bacteria and fungi result in major yield and economic losses, while heavy reliance on synthetic pesticides raises environmental and health issues. This has driven interest in sustainable disease management strategies. Plants produce diverse secondary metabolites that play key roles in pathogen defense, making them valuable resources for biocontrol. Current eco-friendly approaches to crop protection include beneficial organisms, microbial agents, signalling compounds, and natural products from plants, microbes, algae, animals, or minerals. Among these, plant-derived essential oils (EOs) are increasingly studied for agricultural use due to their broad biological activities, including antimicrobial, insecticidal, antioxidant, and anti-inflammatory effects. However, their effectiveness in the field is often limited by rapid degradation and low persistence.

Essential Oils (EOs): Essential oils are natural plant metabolites involved in defense and pollinator attraction, found in tissues such as leaves, stems, and seeds. They give plants their characteristic scent and flavour, are usually less dense than water, and dissolve in organic solvents. Owing to their complex

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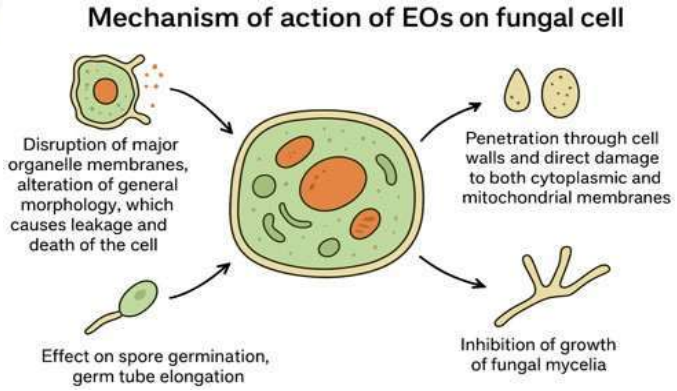
composition, they show diverse biological effects, including antimicrobial, insecticidal, antioxidant, and anti-inflammatory activities. Their chemical profile varies with factors like the plant part, developmental stage, extraction method, and environmental conditions. Phenolic-rich essential oils, such as those containing thymol, carvacrol, eugenol, cinnamaldehyde, geraniol, and citral, exhibit strong antimicrobial effects by disrupting microbial membranes and inducing cell death. Their efficacy depends on chemical composition, pathogen type, concentration, and application method. Delivery approaches, including foliar sprays, soil treatments, or volatilization, can alter outcomes; for instance, clove oil soil application has been shown to reduce seedling diseases in peanuts. Optimized formulations and dosages are therefore critical for consistent performance.

Extraction strategies for essential oils of plant origin: Essential oils can be obtained through either conventional or advanced extraction techniques, and the chosen method strongly influences the yield, composition, and structural integrity of the oil. Hydrodistillation, one of the oldest approaches, involves boiling plant material in water, with a condenser collecting the vapours and a separator isolating the oil from water. Other classical processes include vapor-hydrodistillation, steam distillation, and hydrodiffusion. In contrast, modern technologies such as supercritical carbon dioxide (CO_2) extraction and microwave-assisted methods offer faster processing and reduced solvent consumption. Supercritical CO_2 is particularly efficient at recovering volatile constituents, while microwave-based procedures exist in several forms, including solvent-free microwave extraction and microwave hydrodiffusion.

The potential of essential oils for plant disease management: Essential oils are typically derived from the non-woody parts of plants, particularly the leaves and stems, most commonly through hydrodistillation. They are complex mixtures containing terpenoids along with various aromatic compounds such as phenols, oxides, ethers, alcohols, esters, aldehydes, and ketones, which together define the characteristic aroma and fragrance of the producing species. The presence of volatile monoterpenes and other essential oil constituents plays an important ecological role, providing plants with protection against herbivorous insects and pathogenic fungi. In agricultural applications, the use of essential oils as seed treatments has shown promise for reducing seed-borne infections. The antimicrobial effectiveness of volatile oil constituents can be assessed by inhibition-zone diameters, which are often categorized into six levels ranging from negligible to very high activity. Studies have reported that oils such as lavender, tea tree, cinnamon, peppermint, cassia, and oregano exhibit moderate antifungal effects, while thyme, rosemary, and lemongrass demonstrate stronger inhibitory potential. These results highlight that volatile constituents from certain oils are effective against both bacterial and fungal pathogens.

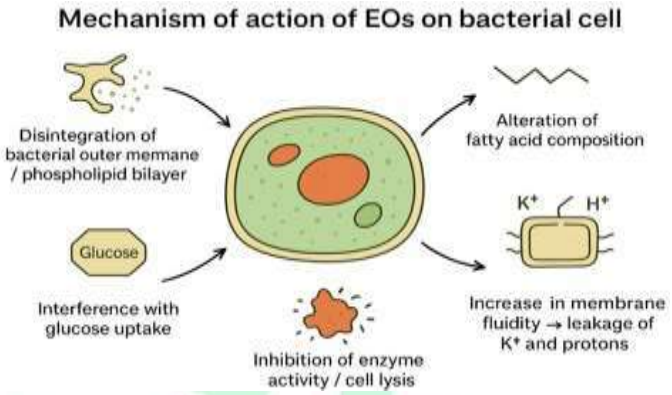
Cassia, tea tree, thyme, and rosemary generally show broader antimicrobial spectra, whereas oils such as clove, wild orange, ylang-ylang, and fennel tend to be less active. The antimicrobial properties of essential oils are evident not only when applied directly but also in their airborne state, where evaporated compounds inhibit microbial growth. Terpenes represent the dominant class of molecules responsible for their fragrance and bioactivity, functioning in both liquid and vaporized forms. Interestingly, whole essential oils tend to exhibit stronger antimicrobial effects compared to individual isolated constituents. For example, rosemary oil contains 1,8-cineole, α-pinene, and camphor as its principal components, and while each of these compounds individually shows some antimicrobial activity, their combined presence in crude rosemary oil results in a more pronounced effect.

Use of EOs against phytopathogenic fungi: Essential oils are naturally occurring plant metabolites with strong antifungal activity, primarily due to constituents such as geraniol, geranyl acetate, linalool, and β-carophyllene. Their mode of action involves penetrating the fungal cell wall, disturbing the structure of organelle membranes, and modifying membrane permeability, processes that eventually result in cell death. These oils are also capable of interfering with different developmental stages of fungi, including spore germination, elongation of germ tubes, and extension of mycelia. Thymoquinone, a compound isolated from black cumin seed oil, has been reported to impair fungal cell walls and membranes. Experimental studies have shown that clove oil completely suppresses the growth of *Botryodiplodia theobromae* and *Rhizoctonia solani* at 250 ppm, and *Fusarium oxysporum* at 500 ppm. Similarly, onion oil prevents the growth of *R. solani* at 250 ppm, *F. oxysporum* at 750 ppm, and *B. theobromae* at 1000 ppm. In addition to these, clove, cinnamon, and several other essential oil constituents demonstrate inhibitory effects against a range of phytopathogenic fungi. Oils from clove, thyme, and peppermint have also been shown to suppress mycelial growth and control bean root rot under both laboratory and greenhouse conditions. Furthermore, treating seeds with essential oils in combination with the beneficial fungus *Trichoderma harzianum* has proven to be an efficient, environmentally safe, and economically viable approach for the management of soil-borne plant diseases.



Use of EOs against phytopathogenic bacteria: Gram-positive bacteria are generally more vulnerable to hydrophobic substances such as essential oils (EOs). This difference in susceptibility is largely due to structural variation in their cell envelopes. Gram-positive species possess a thick peptidoglycan layer associated with hydrophobic

molecules like proteins and teichoic acids, which allows easier penetration of essential oil constituents. In contrast, Gram-negative bacteria have a more complex architecture, consisting of an outer membrane connected to the underlying peptidoglycan layer via lipoproteins. The outer membrane, enriched with proteins and lipopolysaccharides (particularly lipid A), acts as a barrier, making these bacteria more resistant to hydrophobic EO compounds. The antibacterial effects of essential oils can occur through multiple mechanisms, including: (1) damage to the outer membrane or phospholipid bilayer, (2) modification of the fatty acid profile, (3) enhanced membrane fluidity leading to the leakage of potassium ions and protons, (4) disruption of glucose uptake, and (5) suppression of enzyme activity or induction of cell lysis. Among specific examples, citral the main constituent of lemongrass oil exhibited greater bactericidal activity than conventional antibiotics such as ampicillin, streptomycin, and chloramphenicol against certain bacterial strains. Similarly, palmarosa oil demonstrated stronger antibacterial activity than streptomycin against *Xanthomonas oryzae* and *X. malvacearum*. Peppermint oil showed significant activity against *Pseudomonas syringae* pv. *phaseolicola*, producing an inhibition zone of 39.5 mm, comparable to tetracycline (40 mm at 1.6 mg mL^{-1}). In addition, essential oils from palmarosa, lemongrass, and eucalyptus effectively suppressed *Ralstonia solanacearum* race 4 under in vitro conditions and reduced bacterial wilt in edible ginger. Field trials in tomato cultivation also revealed that soil biofumigation with thymol and palmarosa oil decreased the incidence of bacterial wilt. Likewise, clove oil significantly inhibited the growth of *R. solanacearum* in vitro and markedly reduced bacterial wilt severity in tomato plants, without causing phytotoxic effects on seedlings.



Conclusion

Essential oils are naturally occurring plant compounds with notable antifungal and antibacterial properties, positioning them as promising environmentally friendly options for plant disease management. Their integration with biological control agents can enhance effectiveness against pathogens. Owing to their rich and varied chemical composition, essential oils provide broad-spectrum activity and support sustainable farming practices. However, limitations such as low stability in the field, variations in composition, and the high cost of extraction highlight the need for continued research and improved technologies to increase their durability and practical applicability.

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Climate Change and Vegetable Farming in India: Threats and Resilience Strategies

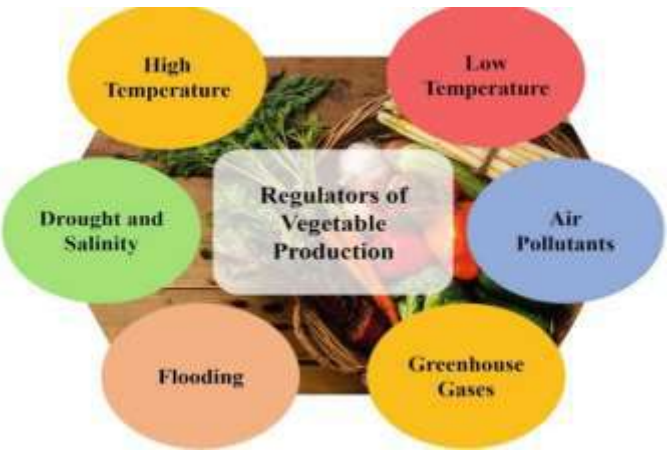
Ayusha Gupta

Abstract

Vegetable crops are essential for human nutrition and rural incomes, but they are facing growing threats from climate change. Rising temperatures, unpredictable rainfall, prolonged droughts, waterlogging, soil salinity, higher CO_2 levels, and ozone pollution are causing major losses in both yield and quality across India's vegetable-growing areas. To address these challenges, several practical measures have been developed and put into action. Climate-resilient varieties, grafting techniques, and seed priming improve plant tolerance to stress. Using plant growth regulators and plant growth-promoting rhizobacteria supports physiological resilience in tough conditions. Climate-smart farming practices like drip irrigation, mulching, and adjusted sowing dates help use resources efficiently and avoid peak stress times. Protected farming through polyhouses and net houses protects crops from extreme weather and allows for off-season production. Incorporating these adaptive methods into vegetable production systems is crucial for reducing climate-related risks, boosting crop resilience, and ensuring nutritional and economic security in a changing climate.

Introduction

Vegetables play a crucial role in our diet, offering a variety of essential vitamins, minerals, and antioxidants that our bodies need. They also represent an important source of income for millions of small-scale farmers across India. However, this critical part of our agricultural landscape is facing serious challenges due to climate change. Issues like frequent droughts, extreme weather fluctuations, unpredictable rainfall, rising soil salinity, and higher concentrations of CO_2 and ozone in the air are all taking a toll on vegetable production, affecting both the quantity and quality of what we grow. This article looks into how climate change is impacting vegetable farming and shares effective strategies, backed by real-life examples, to help strengthen this essential sector against these challenges.



(Source: Bisbis *et al.*, 2018)

Essential environmental factors that influence the production of vegetables

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Climate Change and Its Impact on Vegetable Crops

Heat Stress: An Invisible Scorcher: Heat stress stands out as one of the most harmful abiotic pressures faced by vegetable crops. Take Punjab, for example: during the summer months, the cultivation of tomatoes takes a hit when temperatures soar beyond 38°C. This rise in heat has a detrimental effect, leading to a significant drop in pollen viability. Consequently, the fruit set becomes poor, resulting in yield losses that can reach as high as 40%. Similarly, in Bihar, the high temperatures that occur during the flowering phase of bottle gourd also create challenges. Here, the heat tends to favor the development of male flowers over female flowers, which ultimately impacts fruit set negatively.

Cold Stress: A Silent Killer: Cold stress during the early stages of crops can significantly delay germination and hinder growth. In Himachal Pradesh, when night temperatures drop below 8°C, crops like capsicum and cucumber that are grown in open fields during early spring are severely impacted. This chilling injury results in softening, water-soaked spots, and eventually decay during transport and storage. In Uttarakhand, crops such as peas and French beans often face challenges like flower drop and seed abortion when caught off guard by unexpected cold waves in February.

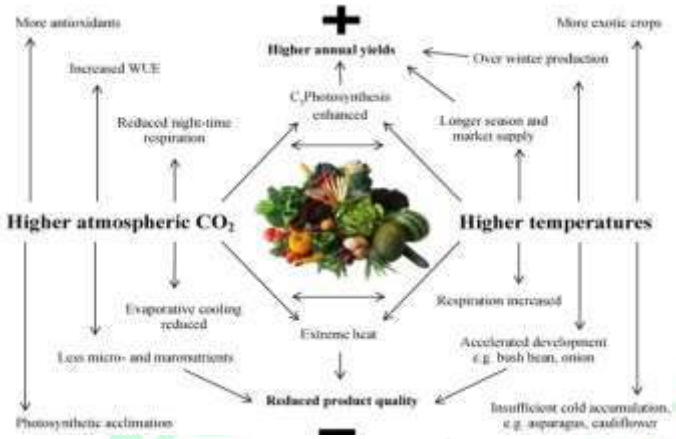
Water Stress: Both Scarcity and Excess Harm: In Bundelkhand, farmers growing tomatoes and okra face a significant challenge due to a lack of adequate irrigation. When water is scarce during the flowering stage, tomato yields can plummet by as much as 60%. Meanwhile, in eastern Uttar Pradesh, onion crops frequently suffer from waterlogging during the monsoon season. A study on the onion variety Arka Kalyan revealed that just a week of standing water could slash bulb yields by nearly 50%. This happens because of oxygen shortages in the roots and the emergence of foliar diseases, such as purple blotch.

Salinity Stress: A Growing Threat in Coastal and Canal Areas: In regions like Gujarat and Tamil Nadu, excessive irrigation and saline groundwater are causing serious salinization issues for vegetable fields. In the Kutch area, crops like okra and carrots are showing signs of distress leaf tip burn and stunted growth due to high soil electrical conductivity, exceeding 6 dS m^{-1}. Pea plants exposed to salinity levels of 8 dS m^{-1} faced a dramatic 50% decrease in both seed germination and plant height when compared to the control group.

Elevated CO_2: Quantity vs Quality Dilemma: While boosting CO_2 levels can enhance biomass and yields, it often comes at the cost of nutritional quality. For instance, in controlled experiments at IIHR Bengaluru with elevated CO_2 levels of 550 ppm, tomato plants did indeed produce more fruits and larger sizes. However, this increase was accompanied by a decrease in flavonoids and vitamin C, ultimately impacting both taste and nutrition.

Ozone Pollution: A Hidden Crop Destroyer: Ozone (O_3), a harmful air pollutant, infiltrates leaves through stomata, leading to oxidative damage. Research conducted in the Delhi-NCR region revea-

led that Palak (Beta vulgaris) plants exposed to 60 ppb of ozone experienced yield losses of up to 25%. Additionally, tomato crops suffered from diminished fruit size and premature yellowing when they were subjected to high levels of ambient O_3 during the months of April and May.



(Source: Bose *et al.*, 2023)

The relationship between atmospheric CO_2 levels and temperature plays a significant role in determining how plants grow and produce yields.

Adaptive Strategies: From Labs to Land: To tackle the challenges posed by climate change, a variety of strategies have been explored and effectively implemented both in India and around the world.

Climate-Resilient Varieties: Genetic Insurance

Among the most commonly embraced stress-tolerant varieties are:

Crop	Variety	Stress Tolerance
Tomato	Arka Vikas, Pusa Sheetal	Drought, Cold
Onion	Arka Kalyan	Waterlogging
Okra	Pusa Sawani	Salinity
Chilli	Arka Lohit, G4	Drought
Bottle Gourd	Pusa Santushti	Heat & Cold
Cowpea	Arka Garima	Drought

Farmers in Rajasthan who grow Arka Meghali tomatoes have noticed that their crops perform better and yield more consistently, even when faced with dry conditions and rising temperatures above 35°C.

Grafting for Resilience: By grafting sensitive scions onto more tolerant rootstocks, we can enhance a plant's ability to withstand flooding, diseases, and salinity. For instance, in Eastern India, when tomatoes are grafted onto brinjal rootstock like Arka Neelkanth, they show remarkable resilience to waterlogged soils during the monsoon season. Interestingly, in countries such as Korea, over 95% of watermelon crops are cultivated using grafted seedlings.

Seed Priming: A Simple But Powerful Tool: Priming seeds with gentle chemicals like potassium nitrate (KNO_3) or thiourea can significantly boost seedling establishment even in tough conditions. A notable example comes from trials at Punjab Agricultural University, where capsicum seeds treated with hydrogen peroxide and abscisic acid (ABA) achieved a remarkable 100% survival rate under salt stress.

Plant Growth Regulators (PGRs): The application of plant growth regulators like brassinosteroids, melatonin, or salicylic acid can help crops cope better with drought and salinity. For example, research from CAZRI in Jodhpur revealed that applying melatonin to watermelon improved photosynthetic activity and biomass even when faced with salt stress.

PGPR (Plant Growth Promoting Rhizobacteria): Plant growth-promoting rhizobacteria (PGPR) such

as *Trichoderma harzianum* and Bradyrhizobium play a crucial role in enhancing root growth and nutrient uptake under stress conditions. In Karnataka, tomato plants treated with *Trichoderma* outperformed untreated ones in terms of survival during periods of heat and drought.

Climate-Smart Agronomic Practices: In Maharashtra, drip irrigation has become a popular solution for growing tomatoes and capsicum, helping address water scarcity issues. Meanwhile, farmers in Odisha and West Bengal often use black plastic or paddy straw for mulching to retain moisture and control weeds. Additionally, in Jharkhand, shifting sowing dates to avoid the peak heat or monsoon stress has proven beneficial for protecting cauliflower and brinjal crops.

Protected Cultivation: Utilizing polyhouses, net houses, or tunnels provides valuable protection for crops against extreme weather, ultimately enhancing quality. For example, in Sikkim, the cultivation of capsicum and tomatoes in polyhouses has led to income increases of two to three times compared to traditional open-field methods. Furthermore, protected farming has enabled the production of off-season vegetables.

Conclusion

Climate change isn't just a looming threat anymore; it's a pressing issue we face today. Vegetable crops are bearing the brunt of this shift. Farmers all over India are grappling with lower yields, pest problems, and financial setbacks, largely due to heatwaves sweeping through the plains and unexpected rain hitting the hills. Farmers have the chance to turn these hurdles into stepping stones. By embracing climate-resilient crop varieties, making use of advanced farming tools, practicing grafting, utilizing beneficial bacteria, engaging in protected cultivation, and adopting smart irrigation techniques, they can navigate through these tough times.

Agroforestry: Cultivating Climate Resilience and Rural Prosperity

Tarun Tomar, Adesh Singh, Raghavendra Singh, Mohammad Hasanain, Archana Verma and Gajjela Indira

Abstract

Global agriculture must feed a growing population while reducing its climate impact and adapting to change. Agroforestry integrating trees with crops and livestock is a key nature-based solution. It locks away carbon (2-5 megagrams per hectare annually in the tropics), storing it in trees and soil. Agroforestry also builds resilience: trees buffer crops and livestock from extreme heat, cold, wind, and drought. They improve water infiltration (2-3 times higher), increase groundwater recharge (40-60%), and reduce soil erosion (up to 70%). These systems boost biodiversity, hosting 3-5 times more species than single-crop fields, enhancing pollination and natural pest control. Economically, agroforestry diversifies farm income through timber, fruit, fodder and niche products, raising incomes by 20-50% for farmers. Practices like alley cropping, silvopasture, windbreaks and multistrata gardens provide adaptable models. By storing carbon, protecting resources and boosting livelihoods, agroforestry offers a practical path to climate-smart farming and thriving rural communities.

Introduction

Global agriculture faces a defining challenge feeding over 7.8 billion people while grappling with its significant environmental footprint. Accounting for a quarter of the world's greenhouse gas emissions through methane from livestock and rice cultivation, nitrous oxide from synthetic fertilizers and carbon dioxide from land-use changes. The sector is paradoxically both victim and contributor to climate disruption. Erratic weather, droughts, and floods increasingly threaten the very production systems we depend on. This practice deliberately integrates trees and shrubs into crop and livestock systems, creating multifunctional landscapes that tackle environmental and economic challenges head-on. Recognized by the IPCC as a vital nature-based climate solution, agroforestry can sequester 2-5 (Mg) megagrams of carbon per hectare annually in the tropics, while simultaneously boosting farmer resilience and income. It represents not just an alternative, but an

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essential evolution in sustainable land management.

Carbon Sequestration Mechanisms in Agro-forestry

Agroforestry sequesters carbon through interconnected, long-term mechanisms.

Above Ground Biomass: Trees function as living carbon reservoirs. Through photosynthesis, they draw down CO_2, converting it into solid carbon stored within trunks, branches, and leaves a secure deposit locked away for decades. Consider tropical alley-cropping systems using *Gliricidia sepium*: within just ten years, they can accumulate an impressive 20-25 megagrams of carbon per hectare above ground alone, demonstrating rapid atmospheric CO_2 reduction potential.

Below Ground Dynamics: Tree roots orchestrate sophisticated carbon storage beyond simple anchorage. While storing carbon themselves, they release root exudates organic compounds that nourish soil microbes. This microbial activity helps bind carbon into stable soil aggregates. Deep-rooted species like *Prosopis juliflora* function as carbon conduits, transporting it over a meter below the surface, creating a remarkably secure, long-term reservoir safe from surface disturbances

Soil Organic Carbon: The most profound and lasting carbon benefit lies beneath our feet. Continuous inputs of organic matter fallen leaves pruned branches enrich the soil over the system's lifetime. Diverse tree mixtures can boost soil organic carbon by 0.5-1.0 (Mg) megagrams per hectare annually compared to monocultures. This occurs through enhanced organic inputs, improved soil structure protecting carbon, and increased microbial activity forming stable compounds.

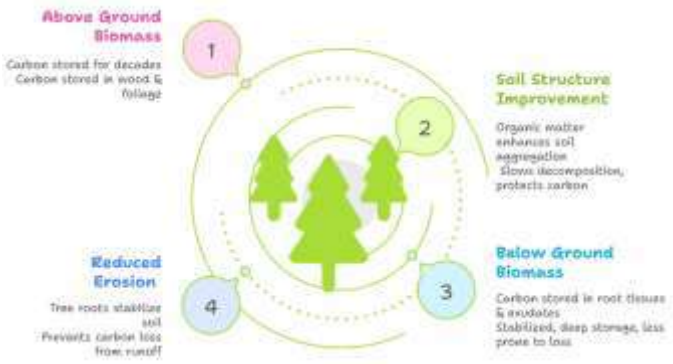

Fig. 1: Agroforestry Carbon Storage Mechanisms

Economic Resilience

Agroforestry fundamentally reshapes farm economics, replacing vulnerability with diversified, resilient income streams:

Timber and Fuelwood: Fast-growing species like *Populus deltoids* or *Eucalyptus camaldulensis* provide harvestable timber and fuel every 5-7 years, meeting local needs and generating commercial income while maintaining carbon stocks through replanting.

Premium Produce: High-value fruit and nut trees (mango - *Mangifera indica*, jackfruit - *Artocarpus heterophyllus*) fetch significantly higher prices than annual grains, offering long-term financial security through extended productive lifespans and access to local and export markets.

Integrate Fodder: Nitrogn-fixing trees like Leucaena *leucocephala* provide protein-rich livestock feed, slashing purchased feed costs. Silvopasture systems create constructive collaboration: animals gain nutrition and shade, while their manure

fertilizes trees and crops.

Specialty Products: Agroforestry unlocks niche markets honey from tree-dependent apiaries, valuable resins or shade-grown medicinal herbs, often commanding premium prices.

The Impact is Clear: ICAR-CAFRI research in India found agroforestry practitioners earned 20-50% more annual income than conventional farmers. This stems from diversified revenue and lower input costs inherent in these integrated systems, with variations based on species selection and market access.

Designing Solutions: Key Agroforestry Systems

Alley Cropping: Rows of trees with crops grown in the alleys. Provides erosion control, allows mechanization, creates beneficial microclimates, and enables continued staple crop production.

Silvopasture: Integrating trees with livestock grazing. Trees offer essential shade (reducing animal heat stress), supplemental fodder, and additional income (timber/fruit), while maintaining pasture productivity.

Windbreaks/Shelterbelts: Tree lines planted along field edges. Protect crops from damaging winds, reduce soil moisture evaporation, regulate microclimates, boost yields in adjacent areas, and provide carbon/economic benefits.

Multistrata Gardens: Mimicking natural forests with layered canopies (trees, shrubs, herbs). Maximizes biodiversity and space efficiency, enabling continuous year-round harvesting of diverse products, ensuring household food security and income.

Table 1: Agroforestry Practices and Benefits

System Type	Key Features	Primary Benefits
Alley Cropping	Tree rows + crop alleys	Erosion control, mechanization, microclimate
Silvopasture	Trees + livestock integration	Shade, fodder, diversified income
Windbreaks/ Shelterbelts	Strategic tree lines	Wind protection, moisture conservation
Multistrata Gardens	Layered canopy (trees/shrubs/herbs)	Continuous harvest, high biodiversity

Water: The Liquid Asset Enhanced

Agroforestry significantly improves watershed health:

Hydrological Buffering: Tree canopies intercept rainfall, reducing soil erosion by up to 70% on slopes. Their root networks enhance water infiltration, achieving rates 2-3 times higher than conventional fields.

Groundwater Security: Deep-rooted species (e.g., *Hardwickia binata* in semi-arid India) create pathways for water percolation, boosting groundwater recharge by 40-60% a critical advantage for water-scarce regions.

Drought Resilience: Trees function as natural buffers. Their shade lowers soil temperature and wind speed, slowing evaporation. Silvopasture systems in Australia show 15-20% better pasture survival during droughts. Alley cropping maintains crop yields within 10-15% of normal even under severe water stress, safeguarding food production.

Biodiversity & Ecosystem Services

Agroforestry landscapes are biodiversity hotspots:

Habitat and Corridors: They create vital wildlife corridors connecting fragmented forests. Multi-layered gardens support 3-5 times more species than

monocrops, hosting beneficial insects, birds and small mammals, acting as stepping stones across farmlands.

Pollination Powerhouse: Flowering trees provide year-round nectar, increasing pollinator diversity by 60-80% compared to treeless farms. Native bee populations thrive, rising 40-70%, directly enhancing crop pollination and yields.

Natural Pest Control: Enhanced habitat diversity fosters robust predator-prey balances, reducing pesticide needs. Bird populations in coffee agroforestry, for instance, provide natural pest control valued at ₹6,260 - ₹25,885 per hectare annually. Beneficial insect numbers surge by 50-150%, significantly curbing pest damage.

Shielding Against a Changing Climate

Agroforestry builds farm-level climate resilience:

Thermal Regulation: Tree canopies create cooler microclimates, lowering crop temperatures by 2-5°C on hot days and providing slight warming (1-3°C) during cold nights, mitigating heat stress on plants and livestock.

Weather Defence: Effective windbreaks slash wind speeds by 50-80% for distances up to 20 times their height, preventing physical crop damage, minimizing wind erosion, and conserving precious soil moisture. Storm damage in protected zones can plummet by 40-60%.

Adaptive Capacity: A mix of species allows farmers to pivot their production focus as climate conditions shift. Income diversification buffers against climate-related crop failures tree products often remain viable when annual crops succumb.

Pathway to Net-Zero Agriculture

Agroforestry contributes to net-zero emissions through multiple pathways. Direct carbon sequestration removes CO_2 from the atmosphere and stores it in biomass and soils. Emission reduction occurs through decreased fertilizer use (as nitrogen-fixing trees reduce synthetic nitrogen requirements), reduced soil erosion and improved water use efficiency. The income diversification aspect ensures farmer adoption and long-term sustainability of these climate-beneficial practices. When farmers see clear economic benefits, they are more likely to maintain and expand agroforestry systems, creating a positive feedback loop between climate action and rural development.

Agroforestry represents a rare convergence of climate science and economic necessity, offering a practical pathway for agriculture to transition from a major greenhouse gas emitter to a carbon sink while simultaneously improving farmer livelihoods. The dual benefits of climate mitigation and income enhancement make agroforestry an essential component of sustainable agricultural development and global climate action strategies.

Conclusion

Agroforestry transcends mere technique; it represents a vital reconciliation between planetary health and human well-being. It offers a practical blueprint for transforming agriculture from a major emissions source into a significant carbon sink, all while enhancing farmers' livelihoods through divers-

ified, resilient incomes. The global imperative for net-zero emissions by 2050, coupled with the rising prominence of nature-based solutions, positions agroforestry as a cornerstone strategy for sustainable development. Meeting the dual challenge of feeding a growing population and mitigating climate change demands fundamental shifts in how we manage our agricultural landscapes. Investing in agroforestry today is an investment in tomorrow: fostering climate stability, ensuring food security and building rural prosperity for generations to come.

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Flowers as Natural Pest Control Agents

Aishwarya Ingole, Aniketkumar L. Bijewar and Rohan Tomar

Introduction

Farmland biodiversity has sharply declined as a result of the intensification of agricultural production, which has simplified farmland landscapes and drastically decreased non-crop habitat area (Wade *et al.,* 2008). The flowering plants that natural enemies of insects rely on for ecological supplies are a major factor in this loss. Simplified agricultural landscapes eliminate insect pests from this natural mortality factor and reduce the overall activity of natural enemies. The use of ecological engineering techniques to enhance pest control has been suggested as a means of achieving agricultural sustainability. Our surrounding is being enriched with many flowers which are known to possess properties that can attract beneficial insects or keep away detrimental insects. The beneficial insects such as ladybugs, praying mantises etc. prey on damage causing pest population whereas honey bees, butterflies, moths etc. serve as potential agent for effective pollination and fruit set. Exploiting flowers as natural pest control agents not only reduces the work pressure but also cuts down the amount of pesticides to be resorted. Lesser pesticide usage can lead to more beneficial bug population, which in turn assist in keeping the harmful bug population in check (Stakal, 2018). There is a saying that "what comes up well in my garden may not come well in yours". It is because every garden out there, avail a discrete growing climate, soil type and so also typical insect pests. Therefore flowers must be chosen which are native to the particular area in order to attract beneficial insects as they have been already acclimatized with the particular flowers. The goal of ecological engineering in this context is to protect crops from economic damage by strategic use of plant biodiversity to maximize natural mortality of pests. It is possible to alter the non-crop vegetation on and near farms to increase the activity of natural enemies, according to recent studies like Thomson *et al*. (2010). This is significant because, especially in agri-environmental systems where farmers may get payment for creating or maintaining noncrop vegetation, noncrop vegetation is frequently established and managed for biodiversity conservation or other purposes unrelated to pest management.

Methods of using flowers for natural pest control

Companion planting

"Companion planting" is one specific type of polyculture, under which two plant species are grown together that are known, or believed, to synergistically improve one another's growth.

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That is, plants are brought together because they directly mask the specific chemical cues that one another's pests use to find their hosts, or because they hold and retain particularly effective natural enemies of one another's pests. In this chapter we define companion plants as inter-plantings of one crop (the companion) within another (the protection target), where the companion directly benefits the target through a specific known (or suspected) mechanism. Compa-nion plants have two ways of controlling insect pests: directly by preventing the development of the pest and indirectly by drawing in natural enemies that subsequently eliminate the pest. It is possible to harvest the perfect companion plant, which will benefit the farmer both directly and indirectly by protecting the goal crop. However, when the economic benefit of higher target yield outweighs the expense of producing the companion, "sacrificial" companion plants which by themselves provide no profit can be beneficial.

Trap cropping: Trap cropping is an attractive option to reduce dependency on conventional pest management practices through insecticides. Indeed, insecticides are costly and hazardous (even the organic ones), and some insect pests have developed resistance against them An example could be the stink bug (Hemiptera: Pentatomidae), which can further be exacerbated by their long life cycle, high capacity to disperse and polyphagous nature leading to a landscape-wide agro-ecosystem threat. Trap crops have been shown to effectively manage stink bugs (*Halyomorpha halys* Stal (Hemiptera: Pentatomidae)) in conventional and organic crop production systems. An efficient trap crop system should have at least double the pest attraction capacity of the cash crop during its vulnerable stage with an easy management strategy and should cover no more than 2-10% of the total crop area (Holden *et al*., 2012).

Different flower crop having pest controlling properties

Borage (*Borago officinalis*, Boraginaceae): Borage is most commonly grown and used in a variety of culinary recipes in Britain. This annual plant yields blue, star-shaped blossoms and works well when used to herbal drinks, tinctures, and leafy green treats. In addition, borage effectively inhibits the growth of cabbage worm (*Pieris rapae*) in cabbage and tobacco hornworm (*Manduca quinquem-aculata*). Additionally, it is said to strengthen plants' defenses against pests and diseases.

Chrysanthemums (*Dendranthema grandiflora*, Asteraceae): The big flower heads of chrysanthemum comes in wide array of colour shades viz. white, pink, yellow etc. and can be made

useful in terms of controlling pests in garden. Some of its cultivars can be brewed to teas which can be served nematicide for killing root nematodes (*Meloidogyne* spp.) in solanaceous vegetable crops (Morton, 2022) and also useful in repelling Japanese beetles (*Popillia japonica*) in corns, soybeans etc. From the flowers of *Chrysanthemum cinerarifolium*, pyrethrum is extracted, which is an excellent pesticide against various insects and safer for human and animal consumption (Smith, 2020). Despites, the flowers attract many butterflies owing to their fragrance, which not only enhance the aesthetic view of garden but also aid in pollination.

Dahlias (*Dahlia variebilis*, Asteraceae): Dahlias' diverse shapes and color hues make them an excellent choice for gardeners and flower enthusiasts. They are also well-known for their ability to repel nematodes and insects, which makes them both aesthetically pleasing and functional.

Four O'Clocks (*Mirabilis jalapa*, Nyctaginaceae): The flowers are known to possess the power for attracting and killing Japanese beetles (*Popillia japonica*) effectively, making them a perfect trap crop to be place planted in the close vicinity of vegetable and flower garden. However, four o' clock flowers can be poisonous to human and pets, thus care should be taken to select a safer site for growing these plants.

Marigolds (*Tagetes* sp., Asteraceae): Many people have acknowledged that marigold has the ability to repel pests. Whiteflies (*Bemicia* sp.) and dangerous nematodes, especially root knot worms (Meliodogyne incognita), can be controlled with French marigolds (*Tagetes patula*). However, the best usage for African marigold (*Tagetes erecta*) is as an irritant for a variety of harmful pests. Marigold cultivars with fragrances are used to make insect repellents. Marigolds are known to repel a lot of harmful insects, but they also draw some unwanted snails (*Cornu aspersum*) and spider mites (*Tetranychus urticae*).

Sunflowers (*Helianthus annuus*, Asteraceae): Being a hardy plant, it comes well in garden and its large flower head attracts a number of beneficial insects such as pollinators like bees, wasps, butterflies etc. Besides, sunflowers can also efficiently drive away aphids (*Aphis gossypii*) from other plants.

Zinnia (*Zinnia elegans*, Asteraceae): These beautiful flower plants not only do establish really quick but also stay long in the garden, thereby ensure continuous crop protection from invading pests for a long period of time. Zinnia attracts pollinating agents as well as ladybugs (*Coccinella septempunctata*), which are predominant natural enemies of aphids (*Aphis gossypii*) and also to some extent can track down some sucking pests like mites (*Tetranychus urticae*), scales (*Pinnaspis aspidistrae*), leaf hoppers (*Circulifer tenellus*), mealy bugs (*Planococcus citri*) etc.

Benefits of using flower plants as natural pest controller

- ✓ Using natural pest control techniques can effectively cut down on the amount of time needed for pest management.

- ✓ A healthier garden in long run can be achieved, as biological pest control ensures negligible residual toxicity by bringing down the pesticide application.
- ✓ Reducing the use of pesticides can lower the carbon footprint by reducing the exposure of humans, pets, plants, water, the environment, and soil to chemical toxins.
- ✓ As compared to chemical methods, the risk of resistance development in pests towards natural methods is comparatively slow.
- ✓ The biological pest control method also makes sure the protection of beneficial pests such as pollinators, as it is target specific.

Conclusion

Pest control is crucial for optimizing growth and yield in a garden. By using less pesticides, companion planting with flowers can be a healthy method of keeping pests away. Natural management guarantees the protection of beneficial insects and natural adversaries, in contrast to harmful chemical pesticides. In order to benefit from the blooms mentioned above as soon as possible, they can be swiftly grown in a garden. To keep dangerous insects and bugs away, these flowers can be planted close to the main crop or cultivated in banks around the garden.

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Aesthetic and Therapeutic Value of Floriculture

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Introduction

Floriculture is a branch of horticulture that is not only concerned with the growth of flowers and ornamental plants but also with their value addition and marketing. Floriculture is an intricate enterprise in India (Shelke, 2014). As urbanization accelerates and green spaces diminish, understanding the aesthetic and therapeutic values of floriculture becomes increasingly important. The production of flowering and colorful plant life for aesthetic and commercial objectives is the specialty of floriculture, a subfield of horticulture. In the world of flowers, various segments play a part in the overall growth of the sector. From beautiful cut flowers and loose blossoms to plants for landscaping, fillers, indoor greenery, turf grass, and even seeds and planting materials- each of these elements contributes to the vibrant tapestry of the floricultural industry. Additionally, the inclusion of value-added products adds an extra layer of richness to the sector's overall growth. It serves a crucial purpose in improving environmental beauty, supporting biodiversity, and fostering economic expansion via international flower trade. Flowers have long been a vital component of human culture, representing feelings, customs, and beauty. In addition to their aesthetic value, they support environmental sustainability by drawing pollinators, enhancing quality air, and reducing urban heat through untested areas. The decorative florist, the subset of floriculture, emphasizes the strategic use of plant life in landscaping to beautify outdoor areas. It expands the past beautification and includes concepts of sustainable landscape, protection of biodiversity and nicely human beings. Sophisticated floral displays in urban landscapes, public parks and personal gardens create a visually attractive, colorful and environmentally beneficial environment. Variants of seasonal shades add dynamic aesthetics, although plants complement the factors of hardcape, soften the built environment and create extra urban spaces. The aesthetic value of floriculture is significant and affects both community dynamics and personal well-being. There is evidence to suggest that being in floral settings can result in happier and less stressful sentiments. The vivid hues, varied forms, and aromatic scents of flowers arouse the senses and foster an environment that encourages creativity and relaxation. A study by Bringslimark *et al*. (2009) found that individuals who interacted with flowers reported higher levels of positive emotions compared to those in non-floral environments.

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Moreover, flowers carry rich symbolic meanings across cultures. They serve as vital components in social rituals and emotional expressions, enhancing their cultural significance. For instance, roses symbolize love and passion, while lilies represent purity and renewal (Hoffman, 2010). Floriculture offers therapeutic advantages in the areas of physical and mental health. Anxiety and depression symptoms have been found to be lessened by gardening and flower-related hobbies. Taking care of plants cultivates mindfulness and enables people to have a profoundly healing connection with nature. Research has indicated that gardening can provide people a feeling of achievement and purpose, which is especially advantageous for those dealing with mental health issues.

Concept of Aesthetics in Floriculture: Aesthetics is the branch of philosophy that deals with the nature of beauty and taste. In the context of floriculture, aesthetics refers to the visual appeal and emotional resonance that flowers and ornamental plants evoke in individuals. This includes aspects such as colour, form, texture and arrangement, all of which contribute to the overall beauty of floral displays.

Flowers as Symbols of Beauty: The human experience is profoundly impacted by beauty. It is frequently linked to inspiration, serenity, and happy feelings. With their vivid hues and elaborate designs, flowers are potent representations of beauty that may improve our surroundings and uplift our spirits. One of the strongest representations of beauty in our surroundings are flowers. Their vivid hues, elaborate designs, and delicious scents produce a sensory impression right away that might improve our mood. According to research, having flowers around can greatly improve emotional health. One study, for example, discovered that people who got flowers expressed more happiness and life satisfaction (Ecoroses, 2024). Flowers also serve as powerful reminders of nature's beauty. The act of caring for plants or simply being surrounded by them fosters a sense of connection to the natural world.

Psychological benefits of Beauty: Flowers have long been celebrated for their beauty, but their emotional impact extends far beyond mere aesthetics. The presence of flowers can evoke a range of positive feelings, from joy and happiness to comfort and connection. The emotional responses elicited by flowers can be understood through various psychological theories. One significant framework is the ecological valence theory, which posits that individuals develop emotional responses to colours based on personal experiences and cultural associations. Flowers have an emotional influence that goes beyond short-term emotions; they also support long-term emotional well-being. People who routinely engage with flowers report decreased levels of anxiety and depression, according to studies. Increased life satisfaction and general pleasure have been associated with the presence of flowers in living areas. Receiving flowers often resulted in happier moods and less irritation, according to a thorough study that looked at participants' behavioral responses over a ten-month

period.

Flowers as Symbol of Connection: Flowers serve as powerful symbols that convey emotions often difficult to articulate. They communicate love, sympathy, appreciation and support without the need for words. For example:

Chrysanthemums: Convey respect and honor.

Red Roses: Symbolize passionate love and desire.

Lilies: Represent purity and devotion.

Tuberose: Represents sensuality and elegance.

Sunflower: Represents adoration, loyalty and longevity.

Jasmine: Represents purity, simplicity and grace.

Marigolds: Signify joy, celebration and auspiciousness.

Hibiscus: Conveys beauty and delicate femininity.

Sweet Pea: Represents blissful pleasure and gratitude for a lovely time spent together.

Therapeutic Potential of Flowers: For generations, flowers have played a significant role in human society due to their aesthetic qualities as well as their medicinal uses. Many nations and historical eras have used flowers in traditional medicine, underscoring their importance in fostering health and wellbeing. Flowers have been used medicinally since the dawn of humanity. For instance, the Egyptians used flowers like chamomile and calendula in their therapeutic regimens. Likewise, the health advantages of numerous flower species have long been acknowledged in traditional Chinese medicine. These traditional methods established the foundation for modern herbal treatment, in which flowers remain an essential component.

Therapeutic Properties of Various Flowers

Pot Marigold (*Calendula officinalis*): It is commonly known as pot marigold, is a flowering plant belonging to the Asteraceae family. It has been used for centuries in traditional medicine across various cultures, particularly in Europe, China and India. The therapeutic applications of calendula are extensive, encompassing treatments for skin ailments, digestive issues and inflammatory conditions. Calendula extracts are widely recognized for their efficacy in promoting tissue regeneration and accelerating wound healing. Calendula exhibits antibacterial and antifungal properties, making it useful in preventing infections in wounds and skin lesions.

Prickly alkanet (*Anchusa strigose*): *Anchusa strigosa* is a flowering plant known for its traditional use in treating wounds and inflammatory conditions. Historically, it has been utilized in folk medicine for

its healing properties. Present in significant amounts, flavonoids contribute to the plant's anti-inflammatory and antioxidant activities.

Hibiscus (*Hibiscus sabdariffa*): Hibiscus is widely recognized for its vibrant flowers and is commonly used in herbal teas. It has a long history in traditional medicine for treating various ailments. Hibiscus's health advantages are attributed to its organic acids, vitamin C, and anthocyanins. It is well known that hibiscus tea can help people with hypertension lower their blood pressure.

Rose (*Rosa* spp.): Roses are not only beautiful but also possess numerous medicinal properties. They have been used in traditional medicine for centuries for their calming effects and health benefits (Josh, 2016). Rose petals can help relieve stomach discomfort and improve digestion.

Lavender (*Lavandula angustifolia*): For generations, lavender has been used in aromatherapy to encourage relaxation because of its well-known relaxing perfume. The calming properties of lavender are attributed to the presence of linalool and linalyl acetate. Essential oil of lavender is frequently used to encourage sleep and lessen anxiety. Due to its antibacterial qualities, lavender oil can aid in the healing of small cuts and burns.

Jasmine (*Jasminum* spp.): Jasmine flowers are prized for their aroma and frequently seen in teas and perfumes. They have long been used to treat a variety of illnesses. The relaxing benefits of jasmine tea on the nervous system are well-known. It has antispasmodic qualities that can help ease menstrual cramps.

Plumeria (*Plumeria* spp.): Plumeria flowers are known for their fragrant blooms and have been used in Ayurvedic medicine for various ailments. Plumeria contains flavonoids and essential oils that contribute to its therapeutic effects. Plumeria decoction is used for treating skin diseases such as rashes or ulcers.

Lotus (*Nelumbo nucifera*): Lotus flowers hold cultural significance in many Asian traditions. They are also recognized for their medicinal properties. Lotus contains alkaloids, flavonoids, tannins, glycosides and other beneficial compounds. Lotus seeds are often consumed to improve digestive health. The fresh lotus seeds were found to have 31.24 mg/ kg of vitamin C, which is an antioxidant and thus has stress coping and improving immunity abilities (Chouaibi *et al*., 2012). These seeds are not only rich in amino acid content and unsaturated fatty acids but also have a considerable amount of polysaccharides, superoxide dismutase (SOD), polyphenols, and other bioactive components.

Evening Primrose (*Oenothera biennis*): The oil that is derived from the seeds of evening primrose is valuable. Traditionally, this oil has been used to treat a number of illnesses. Gamma-linolenic acid (GLA), an omega-6 fatty acid with numerous health advantages, is included in the oil. Premenstrual syndrome (PMS) and menopausal symptoms are frequently reduced by using evening primrose oil.

Sunflower (*Helianthus annuus*): Sunflowers are not only admired for their beauty but also have

therapeutic applications derived from their seeds and petals. Sunflower petals contain flavonoids and antioxidants that contribute to their health benefits. Sunflower extracts have shown potential anti-inflammatory properties useful in treating various conditions. Phenolics compounds possess one or more aromatic rings and with one or more hydroxyl groups. These compounds in diet may provide health benefits associated with reduced risk of chronic disease (Liu, 2007) because they are also known as antioxidants.

Conclusion

The science and art of growing flowering and decorative plants, or floriculture, has many aesthetic and medicinal benefits that improve both the environment and human well-being. This article explores the various functions of floriculture with an emphasis on the psychological effects it has. The aesthetic benefits of floriculture are extensive, and they have an impact on psychological health by elevating mood and lowering stress levels. Research suggests that being in flowery settings might enhance emotions of contentment and calmness. Furthermore, flowers have deep cultural symbolic connotations and are essential to social customs and emotional expression. This symbolism heightens the floral arrangements' cultural relevance in a variety of settings, including memorials and celebrations.

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Last Keystone Species to be Extinct

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Introduction

Species are conserved because they are rare, endemic, large, attractive, or of economic importance. Certain species, known as "keystone" species, should also be protected since they disproportionately impact the survival of all other species. The loss of their habitat puts many species in danger worldwide. Providing sufficient regions of suitably diversified habitat to support viable populations has been the main focus of preservation efforts for the remainder. In the last ten years, statistical models for extinction prediction have been developed as new tools for determining which places are suitable. The population size required to prevent extinction, or the minimum viable population, is the main variable that these models predict. The mathematical tractability, broad applicability, and quantitative predictability of this stochastic extinction theory make it appealing. However, there are still few empirical data to support the idea that population size, and therefore habitat area, is the best predictor of species persistence. The "Keystone species" concept functions as a widespread tool within conservation initiatives. Scientists together with conservationists apply the concept through multiple different approaches. A shared definition is not what creates difficulties with applying the concept in conservation. The actual issue stems from utilizing the concept toward select species when it has wider applicability potential with different species. Through his extensive studies of food web interactions in rocky intertidal habitats, Robert Paine (1966) developed the idea of keystone species. Despite being uncommon in their habitats, their ecosystems undergo substantial changes. We all think that remote regions will experience the disappearance of species. However, the situation is different in practice. The activities that take place in natural settings always go beyond where they started. To survive on Earth, all living things-including humans need to be connected to one another. Society views environmental impacts from humans as a single destructive and extreme interaction between these two parties. Many species worldwide face danger from human-caused events which include deforestation alongside war activities and resource extraction and industrial operations that lead to species displacement. Human survival depends on various natural species which include fungal types in soils and rare pollinators together with an array of

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additional species that most people are unaware of.

Concept of Keystone Species: Paine defines keystone species as organisms which have an unexpectedly prominent effect on their ecosystem when considering their population density. The definition outlined by Davic in 2003 describes this species as one showing powerful interactions while exerting substantial top-down control on species diversity and competitive relationships surpassing its group biomass dominance. An animal species becomes traditional keystone species by preventing a particular herbivorous animal from eliminating the predominant plant species it eats. Keystone predators maintain success even as they remain scarce due to low prey numbers in an environment. The absence of predators would lead prey populations to increase past control levels thus driving the ecosystem into substantial changes through dominating plant extinction.

Table 1: Classification of types of keystone species

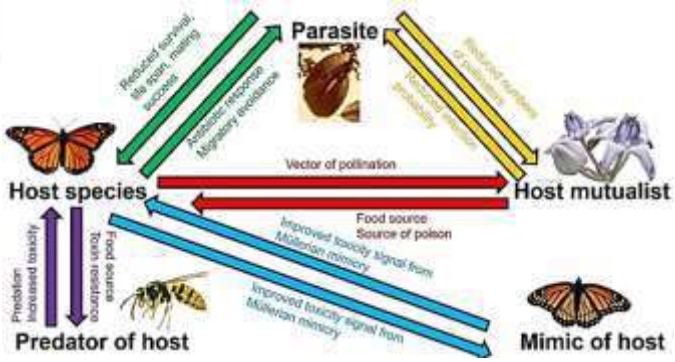
Type	Example
Predators	Marine: otters, sea urchins, kelps Terrestrial: Size-selective seed Predators
Herbivores	Elephants, rabbits
Pathogens, parasites	Myxomatosis, tsetse fly
Mutualists	Plant resources on which key mutualists depend, Pollinators and Dispersers
Earth movers	Rabbits, termitaria and pocket gophers
Abiotic agents	Fire, frost

Keystone species interconnected with agriculture

Beavers: Ecosystem Engineers. Beavers are among the most famous keystone engineering species which people frequently recognize. The activity of dam building by beavers redirects river water to produce and keep wetlands functional.

Hummingbird: The hummingbird serves as a keystone species when it performs pollination services for the Southern Crabapple tree (*Malus angustifolia*). The crabapples produced by the tree post-pollination become a food source for rabbits and deer together with foxes and mice as well as crows and numerous other animals that continue in an endless list.

Prairie dogs: Prairie dogs in their central to western North American habitat foster 130 or more species because they feature as keystone species in the region. The forage availability for livestock together with water conservation and carbon sequestration and preservation of grassland biodiversity in dry areas results from prairie dog (*Cynomys ludovicianus*) soil aerations which create extensive burrows through soil churning and fertilization activities.



Bees: The pollination by bees ensures the survival of one-third of our food supply thus making them vital to nature and agricultural systems. The western honeybee exhibits remarkable climate resilience and agricultural benefits, making it a vital species in various ecosystems. Its adaptability to diverse climates, particularly through subspecies like the heat-tolerant *Apis mellifera* scutellata, enhances its survival in changing environments.

Additionally, honeybees play a crucial role in agriculture by pollinating a significant portion of flowering crops, which is essential for food production.

Earthworms: Of the 140 million tonnes of food annually produced by earthworms the world would rank as its fourth-largest food producer. This production of food allows the global food supply to remain at safe levels. Earthworm populations suffer acutely from exposure to chemical substances including pesticides and fertilizers that kill worms. Health studies show that plants grow up to 30% larger when mixed with vermicompost since this product derives from worm-generated compost.

Owls: The natural predator for seven important agricultural pest rodents are the owl species. Protected owl populations deliver better rodent control by reducing major crop destruction and minimize destructive chemical applications which safeguards environmental diversity. They are natural pest controller.

Wasps: Many tiny fig wasp species live within the tropical area. Figs play a keystone role to maintain the functionality of tropical regions. The flight of fig wasps crosses between 1,000 varieties of fig species. The developing fig fruits maintain their flower components inside their structure. Specific problem insect detection by parasitic organisms results in decreased green fly and caterpillar populations which reduces pesticide requirements. Fig wasps demonstrate exceptional skills as predators which target insects. The use of parasitoids offers plant protection because they do not cause damage to either crops or plants.

Dung beetles: According to their life cycle, the beetles bury their food source in cow dung to sustain their offspring and function as nutrient-rich organisms that optimize soil condition through air circulation and organic material regeneration. When farmers applied 200 pounds of nitrogen to each acre, they obtained yields equivalent to what coastal Bermuda grass generated. Scientists recognized it as a keystone species because it performs decomposition tasks and seed distribution while controlling parasites in grazing areas.

Monarch butterfly: As a biological keystone species the monarch butterfly maintains importance not only in breeding locations but across all areas it travels through. Enhanced condition of these habitats provides multiple positive results for native pollinators as well as other species existing in these habitats. Milkweed provide food for monarch and also support other pollinators by providing nectars.

Global Impact of Keystone Species Loss

Ecosystem collapse and declining biodiversity: The extinction of one species can trigger a trophic cascade, which is a series of extinctions in an ecosystem where keystone species govern population dynamics. For example, when wolves went extinct in some regions, deer populations surged, overgrazing meadows and forests and reducing biodiversity.

Climate Effects and Environmental Instability: A large number of keystone species aid in climate

regulation and carbon sequestration. Whale migration throughout the ocean enables them to substantially contribute to carbon cycle processes. Due to their reduced numbers climate change has intensified and this decline minimized the ocean's ability to take in carbon dioxide. The behavior of elephants controls overpopulation of particular plant species to protect savanna ecosystems. Weather systems are directly impacted by how their disappearance alters plant communities.

Economic and Agricultural Consequences: Worldwide food production depends heavily on keystone species including pollinators among which the most important are bees butterflies and bats. The reduction of wildlife species creates economic challenges together with rising food costs which threatens future agricultural production output. Healthy soil preservation conducted by soil engineers (earthworms and fungi) reduces the need for chemical fertilizers. When these creatures vanish from the ecosystem it triggers both a decrease in agricultural production and increased agricultural costs. Fisheries and marine industries suffer when predator species (e.g., sharks) decline, leading to imbalances in fish populations and collapse of commercial fishing stocks.

Future without keystone species…..

Keystone species extinction is likely to cause long-lasting ecological disruptions. All reactive conservation strategies should be replaced with prior protection measures as the main conservation priority in the years to come. Maintaining biodiversity is as important to human health and survival as it is to the environment. By studying the loss of keystone species, we can find practical solutions to preserve ecological stability and leave a biodiverse Earth for future generations.

Conclusion

The survival of the key species in ecosystems as well as the fundamental structure of their habitat ecosystems are at risk due to a variety of environmental stressors. Keystone species are mostly threatened by habitat loss, habitat fragmentation, overexploitation, climate change and the introduction of invasive species. To preserve these species' ecological importance in ecosystems, conservation plans must give protecting them and their habitats first priority. Our food supply is a direct result of the extinction that humans cause through pollution. Every living species has a vital role in the natural system, which depends on them for processes including seed distribution, aeration, pollination, and wetland management. Our regular coffee habit and all of our nighttime food cravings are at jeopardy when species disappear.

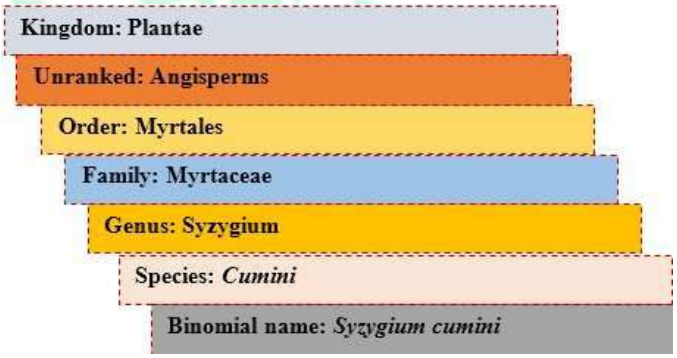
Pharmacognostic and Phytochemical Properties of *Syzygium cumini* (L.)

Ajay S. Zinjade

Introduction

Syzygium cumini Linn. (syn. Eugenia jambolana) Plant is commonly kwon as the Jamun plant in Hindi and Jambhul in Marathi, which is distributed along tropical and sub-tropical regions of world. In India the Jamun plant is distributed in all over the country, it is cultivated and sometime occurs wild. The plant has many medicinal properties, which is used in folk medicine from the ancient periods. This plant belongs to the Myrtaceae family. Although it is a tropical tree but it grows easily in subtropical climates also. *S. cumini* is a fast-growing plant; it can grow up to a height of 30 m and can live for approximately 100 years. Its dense foliage provides shade and is grown just for their fruits and ornamental values (Murti *et al*., 2012). Vitamin C, alkaloids, saponin, gallic acid, tannins, anthocyanins, glucoside, phenolic compound, and other substances have all been shown to be present in jamun plants (Suradkar *et al*., 2015). The plant is well known for its therapeutic and restorative properties and is used to treat a variety of illnesses. Characteristics such as antioxidant, hepatoprotective, antidiuretic, anti-bacterial, antifungal, and many more. The fruit's stunning purple to black hue results from the presence of anthocyanin, which also gives it strong antioxidant qualities. A variant of the tree produces green coloured young fruit and after ripen the fruit converted as purple to black coloured. The fruit has a combination of fragrant sweet, astringent flavour and mildly sour tends to colour the tongue purple. The leaves, stem-bark, fruit and seeds are used in many disease treatments. Leaves, bark and fruits are used for the treatment of diabetes, sore throat, astringent and diarrhoea. The plant powder used for headache, stomach-ache, roughness loss of skin coloration. Seed are used for diabetes, the mature fruit used for indigestion (More *et al*., 2023).

Taxonomical classification



Phytochemical constituents

Jamun is rich in compounds containing anthocyanins, glucoside, ellagic acid, isoquercetin, kaemferol and myrecetin. The seeds are claimed to contain alkaloid, jambosine, and glycoside jambolin or antimellin, which halts the diastatic conversion of starch into sugar and seed extract has lowered blood pressure by 34.6% and this action is attributed to the ellagic acid content. The seeds have been reported to be rich in flavonoids, a well-known antioxidant, which accounts for the scavenging of free radicals

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and protective effect on antioxidant enzymes and also found to have high total phenolics with significant antioxidant activity and are fairly rich in protein and calcium. Java plums are rich in sugar, mineral salts, vitamins C, PP which fortifies the beneficial effects of vitamin C, anthocyanins and flavonoids (Bajpai *et al*., 2005).

Leaves: The leaves are rich in acylated flavonol glycosides, quercetin, myricetin, myricitin, myricetin 3-O-4-acetyl-L-rhamnopyranoside, tritepenoid, esterase, galloyl carboxylase, and tannin.

Stem bark: The stem bark is abundant in quercetin, kaempferol, myricetin, gallic and ellagic acid, bergenins, flavonoids, tannins, betulinic acid, friedelin, epi-friedelanol, β-sitosterol, eugenin, and fatty acid ester of epi-friedelanol. The astringent quality of stem bark may be caused by the presence of gallo- and ellagi-tannins.

Flowers: The flowers are rich in kaempferol, quercetin, myricetin, isoquercetin (quercetin-3-glucoside), myricetin-3-L-arabinoside, quercetin-3-D-galactoside, dihydromyricetin, oleanolic acid, acetyl oleanolic acid, eugenol-triterpenoid-A and eugenol triterpenoid-B.

Fruits: The fruits are rich in raffinose, glucose, fructose, citric acid, mallic acid, gallic acid, anthocyanins; delphinidin-3-gentiobioside, malvidin -3-laminaribioside, petunidin-3-gentiobioside, cyanidin diglycoside, petunidin and malvidin. The sourness of fruits may be due to presence of gallic acid. The color of the fruits might be due to the presence of anthocyanins. The fruit contains 83.70-85.80 g moisture, 0.70-0.13 g protein, 0.15-0.30 g fat, 0.30-0.90 g crude fiber, 14.00 g carbohydrate, 0.32-0.40 g ash, 8.30-15.00 mg calcium, 35.00 mg magnesium, 15.00-16.20 mg phosphorus, 1.20-1.62 mg iron, 26.20 mg sodium, 55.00 mg potassium, 0.23 mg copper, 13.00 mg sulfur, 8.00 mg chlorine, 80 I.U. vitamin A, 0.01-0.03 mg thiamine, 0.009-0.01 mg riboflavin, 0.20-0.29 mg niacin, 5.70-18.00 mg ascorbic acid, 7.00 mg choline and 3.00 mcg folic acid per 100 g of edible portion (Noomrio and Dahot, 1996).

Table 1: Medicinal Importance of Chemicals Present in Leaves

Chemical present in leaves	Medical importance
Quercetin	Decreases DMBA-induced DNA damage
β- sitosterol	Topical application of β-sitosterol inhibited the TPA-induced inflammation.
Myricetin	Inhibits polycyclic aromatic hydrocarbon-DNA adduct formation in epidermis and lungs of SENCAR mice.
Gallic acid	Inhibits the TPA-induced inductions of epidermal ornithine decarboxylase activity, hydroperoxide production and DNA synthesis, and also inhibit the promotion of skin papillomas and carcinomas in the two-step initiationpromotion protocol.
Oleanolic acid	Inhibits tumor promotion ion in mouse skin.

Pharmacological Properties

A range of pharmacological properties is possessed by various extracts of jamun which include antidiabetic, an tihyperlipidemic, anti-hypercholesterolemic, anticancer, car dioprotective, hepatoprotective, neuroprotective, anti-inflam matory, antioxidant, and antimicrobial activities, as established by different scientific studies.

Antidiabetic activity: The antidiabetic effect of many natural products is based on the inhibition

of α-amylase and α-glucosidase activities, which slow down starch digestion contributing to the reduction in blood glucose level. Shinde *et al*. (2008) evaluated inhibitory activ ity of jamun seed extracts against microbial (*Saccharomyces cerevisiae* and *Bacillus stearothermophilus*, in vitro) and mammalian (*in vivo* on Goto-Kakizaki rat intestine, administration of 250 mg kg^{-1} body weight) α-glucosidase. Both acetone and 70% ethanol extracts exhibited inhibitory activity against enzyme of all three sources. Several in vivo studies showed the antidiabetic activity of jamun seeds, their extracts and phytochemicals. Study revealed that jamun seed extract preferably improves various biochemical actions, such as glucose tolerance and glucose uptake, maintains glucose homeostasis in diabetic animals, and exhibits benefits in restoring β-cells.

Antihyperlipidemic & antihypercholesterolemic activity: The presence of several bioactive compounds in jamun seeds helps to regulate the blood lipid profile. Oral infusion of an alcoholic jamun seed extract (100 mg kg^{-1} body weight) in diabetic rats resulted in a significant reduction in serum lipids. In both streptozotocin-induced diabetic rats and alloxan-induced diabetic rabbits, the jamun seed extract also reduced the 3-hydroxy-3-methyl-glutaryl-coenzyme A (HMG-CoA) reductase activity, serum low-density lipoprotein (LDL) cholesterol level, and total serum cholesterol to high-density lipoprotein (HDL) cholesterol ratio (Sharma *et al*., 2003). In Sharma *et al*. (2017) trials, diabetic rats were given 200 and 400 mg kg^{-1} ×day) of a water extract from jamun seeds. In comparison to the diabetic control group, the authors found lower serum levels of LDL cholesterol (by 28.3 and 32.9%, respectively), triglycerides (by 43.1 and 46.7%, respectively), and total cholesterol (by 39.9 and 44.2%, respectively). When extracts were added to the rat diet, the HDL-cholesterol concentration rose by 14.6% and 20.2%, respectively.

Hepatoprotective activity: The ability of jamun peel extract to protect rat hepatocytes from oxidative damage caused by carbon tetrachloride (CCl4). Das and Sarma's (2009) in vivo research on rats' toxicity from paracetamol has further substantiated the hepatoprotective effect. They showed a decrease in the rise of serum enzymes, total protein, and albumin levels due to hepatoprotection, based on the oral administration of an ethanolic pulp extract in a dose-dependent manner. Additionally, the investigation confirmed that the liver's histological structure was intact and that there was no acute oral damage.

Immunomodulatory activity: The term immuno-modulatory means regulation of the immune system by suppression and stimulation of cells and organs of the immune system. It is now being recognized that immunomodulatory therapy could be practiced as an alternative to conventional chemotherapy towards variety of diseased conditions. the methanolic extract of jamun seeds possesses promising immunomo-dulatory activity. While working on humoral and cellular immunity in mice by injecting carbon ink suspension and hemagglutination reaction and

delayed type hypersensitivity response in rats induced by Sheep Red Blood Cell, they reported a significant increase in total white blood cell, neutrophils and lymphocytes count in dose-dependent manner (Barh and Vishwanathan, 2008).

Antibacterial activity: A recent study conducted by Patel and Rao (2010) found that jamun pulp has antimicrobial properties. The study used extracts from several fruit pulp maturity indices (young, premature, mature, preripened, and ripened) and solvent systems (ethyl acetate, acetone, methanol, aqueous, and diethyl ether). Gram positive bacteria were said to be more susceptible to the extracts' effects than Gram negative ones. The most promising antibacterial agent among the various maturity stages and solvents was the diethyl ether extract from preripened pulp.

Cardioprotective activity: A study found that the methanolic extract of jamun seeds helped protect albino rats' hearts from myocardial infarction caused by isoproterenol. The effect was probably related to strengthening of the myocardial membrane, induced by the phytochemicals like alkaloids, amino acids, flavonoids, glycosides, phytosterols, saponins, steroids, tannins and triterpenoids in the extract.

Conclusion

Jamun (*Syzygium cumini*), sometimes referred to as Java Plum, Blackberry, or Black Plum, is a huge, glabrous, evergreen tree that grows all throughout India. The trees bear rectangular or ellipsoid berries every year. When fully ripe, they turn purple black, yet when raw, they are green. The ripe fruits have a little tangy and sweet flavor. According to studies, the berries include minerals, carbohydrates, and pharmacologically active phytochemicals such as anthocyanins, terpenes, and flavonoids. Phenolic and other non-phenolic bioactives are abundant in the entire jamun, which includes the peel, pulp, and seed. The most extensively researched of them is the ameliorating activity against Type 1 and Type 2 diabetes. Pharmacological studies link the phytochemicals to a variety of therapeutic actions, including antioxidative, anti-cancer, antidiabetic, antibacterial, and radioprotective activities.

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Burlapping: Importance and Application in Floriculture

Aniketkumar L. Bijewar, Aishwarya Ingole and Ajay Baldaniya

Introduction

Burlapping is the practice of wrapping plant root systems in burlap fabric, has been a cornerstone of horticulture for over a century. This technique is particularly vital in floriculture, where the safe transport and transplantation of trees, shrubs, and ornamental plants are critical to their survival. Originating in the early 20th century, burlapping emerged as a solution to the challenges of moving large plants without damaging their delicate root systems. By encasing the root ball in burlap, growers minimize root disturbance and moisture loss, significantly enhancing plant survival rates. Natural burlap, traditionally made from jute fibers, remains the gold standard due to its biodegradability and ability to retain moisture. However, the horticultural industry has evolved, incorporating synthetic and treated burlap variants to address specific needs. Modern practices integrate burlapping with advanced techniques such as growth regulators, in vitro propagation, and mechanized planting, further improving plant resilience. Beyond commercial horticulture, burlapping plays a pivotal role in ecological restoration, enabling the successful transplantation of native species in degraded eco-systems. Transplanting trees is an age-old technique, often employed to preserve, maintain or rescue trees that are in danger of being cut down, damaged or destroyed. Burlapping is the process of relocating a mature tree from one location to another. This method involves significant intervention and trees often need time to recover afterward. Due to the expansive shape and spread of a tree's root system, transplantation typically results in the loss of a considerable number of roots. Today, the practice of moving mature trees upright with their full canopies intact and without pruning or bending branches is increasingly common in premium construction projects, especially those with commercial or green heritage value. Remarkably, trees ranging from 50 kilograms to as much as 50 tonnes have successfully been relocated (Sunil, 2024).

Types of tree transplantation

Bare root: Bare root plants are dug out from nursery fields in the spring or fall. After the soil is removed from the roots, plants are stored in a temperature and humidity-controlled environment during the winter. Before they begin to grow, plant them in the early spring because they are easier to dig, store, and ship, trees generated using this method can be produced at a lower cost than trees produced using other systems (Clatterbuck and Vandergriff, 2012).

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Packed stock: Packaged trees and shrubs are bare-root plants with their roots packed with shingle tow, peat moss, or another moist material. Before they start to grow, plant them in the early spring. Keep the contents moist and the packaging dark and cold before planting. Handle these plants like bare root plants.

Field- Potted: Nursery stock that has been produced in the field and subsequently potted refers to plants that have been dug out with the ball of soil still attached. As field dirt won't support healthy plant development in a container, sell and plant them in the spring. As little as possible should be disturbed while planting and excavating.

Containerized: Containerized trees and shrubs are removed as bare root material from the nursery in the spring or fall. They are then put in a container with a unique growth media before being sold.

Container grown: Container-grown stock has grown in a container for the majority of its existence. Container-grown plants experience less transplant shock since their roots are not disturbed while planting. Plant them at any time during the growing season. Girdling roots may result from deformed root systems in plants that have outgrown their pots. Large plants may get root rot in the container. To remove any future girdling or circular roots, the root balls of these plants must be split apart or pushed apart.

Balled and Burlapped (B&B): Trees and shrubs that have been balled and burlapped are planted with a hard ball of earth around their roots and are then held firmly in place with burlap, twine, and occasionally a wire basket. The roots may suffer severe harm as a result of a fractured, damaged, or dry soil ball. In the soil ball, the stem shouldn't bob up and down. In the spring, summer, and fall, plant B&B stock.The primary disadvantage to B&B trees is that usually 95 percent of the original root system of the tree is left in the field.

Tree spade: A tree spade, a tool that digs up a mass of dirt that includes the plant and some of its roots, is frequently used to relocate larger plants. The diameters of tree spades for evergreen and deciduous trees differ.There are 2 types of tree spades available which are 90D and 100D.

Importance of Burlapping in Floriculture

Enhanced Plant Survival: Burlapping's capacity to safeguard root systems during transplantation is its main advantage. While bare-root plants are susceptible to mechanical harm and desiccation, balled-and-burlapped (B&B) plants preserve the integrity of their roots. According to a study on green ash trees transplanted into arid conditions, B&B specimens outperformed their bare-root counterparts in terms of survival rates by 20%. During the crucial post-transplant phase, the burlap kept the roots hydrated by retaining moisture around them.

Environmental Sustainability: Natural burlap's biodegradability makes it an eco-friendly alternative to plastic wraps. As it decomposes, it enriches soil with organic matter, aligning with sustainable horticultural practices. Unlike synthetic materials, burlap does not contribute to microplastic pollution,

making it ideal for organic farming and conservation projects.

Moisture and Aeration Balance: Burlap's porous structure allows oxygen to reach roots while retaining moisture a balance critical for root health. This prevents anaerobic conditions that lead to root rot. In a study on ornamental shrubs, burlapped plants developed denser root systems compared to those wrapped in non-porous materials.

Reduced Transplant Shock: Transplant shocka stress response caused by root disturbanceis mitigated by burlapping. By stabilizing the root environment, burlap minimizes stress, enabling quicker recovery. Research on urban landscaping projects showed burlapped trees resumed growth 30% faster than non-burlapped ones.

Applications of Burlapping

Root Ball Protection: Burlap secures root balls during transit, reducing mechanical stress. In a case study, burlapped magnolia trees transported across 500 miles exhibited no root damage, whereas 15% of bare root specimens failed to establish.

Winter Protection: In cold climates, burlap shields plants from frost heave and windburn. Wrapping evergreen shrubs in burlap reduced winter dieback by 40% compared to unprotected plants.

Erosion Control: On slopes, burlap stabilizes soil and promotes vegetation growth. A reforestation project in the Himalayas used burlap mesh to reduce soil erosion by 50%, enabling successful sapling establishment.

Mulching Alternative: Burlap sheets suppress weeds and retain soil moisture. In drought-prone regions, burlap mulch reduced irrigation needs by 25% while improving soil organic content.

Conclusion

Burlapping, the practice of wrapping plant root systems in burlap fabric, is a cornerstone technique in floriculture, ensuring the survival and health of transplanted specimens. This review highlights its historical evolution, ecological significance, and modern applications. By protecting root balls during transport, burlapping minimizes mechanical damage and desiccation, improving plant survival rates by up to 20% compared to bare-root methods. Natural burlap, biodegradable and derived from jute, remains favored for its sustainability, though treated and synthetic variants offer durability in specific contexts. Key applications extend beyond root protection to winter shielding, erosion control, and soil moisture retention, underscoring its versatility.

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Medicinal Properties of Cucurbits

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Introduction

Consumption of some fruits is strongly associated with several health benefits due to their high nutritional value and properties in risks reduction of certain illness such as cancers, cardiovascular diseases and cataracts fully justified and attributed to the presence of bioactive compounds (BCs) in the plant matrices (Shofian *et al*., 2011). Due to their centuries-old medicinal properties, vegetables are utilized as medicine in many nations; their use has grown to be a significant component of daily diets throughout individuals. Any vegetable's ability to heal depends entirely on its phytochemicals and various chemical components. The term "pytochemical" refers to substances that are not recognized as food nutrients but that have therapeutic properties for a variety of human ailments. Various vegetable parts, including flowers, fruits, leaves, stems, petioles, and roots, are employed as medicines in traditional medical systems. Cucurbitaceae (Cucurbit) is an important family comprising one of the most genetically diverse groups of food plants. Most of the plants belonging to this family are frost sensitive and drought-tolerant. Some important Cucurbit family members include gourd, melon, cucumber, squash and pumpkin. Muskmelon is considered to be native of Persia (Iran) and adjacent areas on the west and the east. Central Asia comprising southern Russia, Afghanistan, Pakistan and north-west India is regarded as its secondary centre. Muskmelon had been cultivated in Egypt since 2400 BC. Vegetable crops known as cucurbits are members of the family Cucurbitaceae, which includes 750 species and 90 genera that are used in a variety of ways for human consumption across the globe. Cucurbits are a diverse family that includes salad crops like cucumber and long melons, dessert fruits like water and musk melons, and culinary crops like bitter gourd, bottle gourd, and pumpkin. Nearly all of the nutrients needed for human health are found in cucurbits, including sugar, protein, carbohydrates, vitamins, minerals, and other nutrients (Vanam, 2007). The various species within this family are rich in phytochemicals that exhibit a broad spectrum of bioactivities. These plants were used in ancient civilizations for healing wounds, detoxifying the body, and treating conditions such as jaundice, kidney disorders, and respiratory diseases (Chen *et al*., 2024). In regions like India, China, and Africa, cucurbit-based formulations have been included in traditional healing practices for generations, often in

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combination with other herbs to enhance their effectiveness.

Bitter Gourd: The fruit acts as an anthelmintic, stomachic, antibilious and laxative. In fact, it is a tonic fruit, used in rheumatism, gout and also for diabetes. The juice of fresh leaves is given to children as a mild purgative but is not un-attended with danger. In case of migraine, the juice of a leaf is prepared in which a little salt is mixed, and then a drop is put into nostril, the same side as the migraine just once. In case of burning soles, the juice of tender leaves is just applied at bed time for seven days7. The root of bitter gourd has an abortifacient effect. A decoction of the root extract is helpful in abortion, hemorrhoids and also in biliaesness.

Cucumber: The excessive internal heat is supposed to be detrimental to body system. If the body keeps burning continuously more than necessary, the effect on the person is in extreme exhaustion. Cucumber juice is highly recommended. For quick symptomatic cooling of the head, hand and feet, cucumber paste when applied on the body part is very effective in bringing a refrigerator effect. It should be noted that cucumber juice is frequently used to treat gum and tooth disorders. Its juice continues to be beneficial for rheumatism and healthful hair growth. The seed possesses diuretic and tonic qualities that make it useful in medicine.

Ridge Gourd: In case of jaundice, the juice is prepared from the leaves and every morning 2-3 drops are put into nose for four days. Anus tag: A paste of root is prepared with a little water. Then it is applied at the anus for ten nights. In local treatment, leaves are used as poultice in haemorrhoids, leprosy and splenitis; juice in conjunctivitis; decoction for uraemia and amenorrhoea. Ripe seeds are emetic and purgative.

Sponge Gourd: The plants contain a compound called luffein. Juice from the leaves are use to cure conjunctivitis of the eye. The leaves and fruits are good remedies for Jaundice. Roots have laxative effects and the oil from the seeds is used for cutaneous complains.

Snake Gourd: While the fruits are served as an appetizer, the leaves and stems are utilized to heal skin conditions. The seeds have the ability to deworm.

Sweet Gourd: While seeds are used to cure chest issues and encourage urine production, fruits are used to treat ulcers, piles, sores, and obstruction of the liver and spleen. Pile removal, migraines, excessive perspiration, coughing, and stones can all

be effectively treated with roots.

Pointed Gourd: Commonly used for digestive issues, the leaves and stems include hypocholesterolemic, hypoglyceridimic, hypoglycemic, and hypophospholipemic properties. Fruits are excellent mouth fresheners and can be used to cure blisters, wounds, and fever. The roots are an effective treatment for ascites and a diuretic. *Trichosanthes dioica* herbage is widely used to cure a variety of human ailments.

Bottle Gourd: The leaves are used to control skin disease. Roots are used against osteoarthritis. The fruits are widely used as antidiabetic, anti-anaphylactic and antihistaminic. Fruits are also used for the treatment of leprosy, fever, asthma, bronchitis and jaundice.

Ash Gourd: Ash gourd has strong therapeutic and restorative qualities and is nutritious and healthful. People with diabetes and obesity can benefit from it because the fruit has a low calorie content. The fruit has cooling, diuretic, styptic, purgative, and tonic properties. As a blood coagulant, the fruit juice helps treat respiratory issues, peptic ulcers, hemoptysis, and other internal hemorrhage discharges from the kidneys, lungs, and stomach. Regular use reduces inflammation in the digestive system, diabetes, and piles dyspepsia. It also relieves in periodic attacks of hysteria, convulsion and other nervous diseases. The fruit increase the secretion and discharge of urine, washing out toxins from body system. In case of general debility, a delicacy from fruit pulp by boiling its pieces in water and water and adding sugar to it is used as a domestic recipe to increase weight, in T.B., heart weakness, heart in the body, thinness of semen and anaemia.

Pumpkin: While fresh pulps can be used as a poultice for boils, burns, and inflammations, seeds have diuretic and tonic properties. Young branches and leaves have a slight laxative effect. To alleviate night blindness, the year-old pumpkin is simply cooked with water and taken on a regular basis for approximately a week.

Watermelon: Due to its 90% water content, which acts as a natural diuretic to cleanse the kidneys and bladder, it is consumed all over the world. Especially advised for pregnant and menstruating women who retain fluids. Malnutrition, typhoid fever, tiredness, and scanty urination are all treated with the plants.

Muskmelon: The plants are used against scanty urination, anaemic scanty urination, loss of appetite, vomiting, problems in prostate gland and wound in urinary tract.

Conclusion

India has a climate that is ideal for growing a variety of cucurbitaceous crops. There is a wide variety of cucurbits in the farmhouse gardens of many states and communities. Crop species and cultivars vary in a variety of morphological characteristics. This varied biodiversity has several ehymetic qualities that could help the most underprivileged members of society with their basic medical requirements. A rich source of bioactive substances with enormous therapeutic potential are cucurbits. They are an essential component of both

conventional and contemporary medicine because to their anti-inflammatory, anti-cancer, antibacterial, antioxidant and cardioprotective qualities. Nevertheless, despite their many health advantages, cucurbits also carry a toxicity risk since they contain cucurbitacins, which can upset the stomach and, in extreme situations, harm organs. Cucurbit-based goods, particularly those in pharmaceutical form, should be consumed with caution by people who already have health issues.

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Biodiversity as Wealth

B. Bhavani, Sapna B. and Sumana K.

Introduction

The diversity in the living organisms present on the earth, collectively in land, water and air is called biological diversity or biodiversity. The term biodiversity (from "biological diversity") refers to the variety of life on Earth at all its levels, from genes to ecosystems, and can encompass the evolutionary, ecological, and cultural processes that sustain life. It includes the concepts of species diversity, habitat diversity and genetic diversity. Genetic diversity: the genetic range that is present in a population of a species. Species that have a small genetic diversity are more at risk of being wiped out by diseases. Selective breeding by humans to domesticate animals or grow plants with specific traits has reduced the gene pool in many species. Species diversity: the range of species living in a specified area. An area may have a high density of wildlife, but if they are all from a few different species then it would have low species diversity. Habitat diversity: the range of different habitats in an ecosystem. Jungle or forest ecosystems are likely to have higher habitat diversity than desert or tundra ecosystems. Biodiversity includes millions of races, local variants of species and subspecies, and ecological processes and cycles that link organisms into populations, communities, ecosystems and ultimately the entire biosphere. Biodiversity is mainly recognized at three levels, namely, genetic, species and ecosystem. Genetic diversity refers to variation within individual species; species diversity pertains to the variety of species; and ecosystem diversity refers to diversity of ecosystems and habitats. On the basis of the above classification, the global biodiversity has 1.75 million identified species (Venkataraman and Latha, 2008). These organisms are found in various environments in various combinations. Just 2.7 lakh of these 1.75 million species are plants kingdom. Less than 9,000 plant species provide the majority of the food, clothing, shelter, medicine, fodder, and industry that humans rely on. Approximately 168 of these species are explicitly grown for food and agriculture, out of the approximately 900 species that have been domesticated for agricultural purposes. Many plant variations are declining at an alarming rate as a result of growing agricultural industrial-ization and human reliance on plant species. Moreover, distribution of biodiversity within this

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narrow equatorial region is also not uniform. As per the Millennium Ecosystem Assessment, climate change is likely to become one of the most substantial drivers of biodiversity loss by the end of the present century. Climate change is imposing severe threats to, and having dramatic effects on, a wide range of India's plants and animals (Ray *et al*., 2014). Maintaining and restoring healthy ecosystems plays a key role in adapting to and mitigating climate change through biodiversity conservation, sustainable use, and sustainable land management which yield multiple environmental, economic, and social benefits.

Biodiversity is our living wealth. It is a result of hundreds of millions of years of evolutionary history. Biodiversity can be discussed at three levels: (i) Genetic diversity; (ii) Species diversity; (iii) Ecosystem diversity.

Genetic Diversity: Genes are the basic building blocks of various life forms. Genetic biodiversity refers to the variation of genes within species. Groups of individual organisms having certain similarities in their physical characteristics are called species. This genetic diversity is essential for a healthy breeding of population of species.

Species Diversity: This refers to the variety of species. It relates to the number of species in a defined area. The diversity of species can be measured through its richness, abundance and types. Some areas are richer in species than others. Areas rich in species diversity are called hotspots of diversity.

Ecosystem Diversity: Ecosystem diversity is made up of the wide variations among ecosystem types as well as the variety of habitats and ecological processes that exist within each type. At Terrestrial biodiversity is higher at the equator than at the poles. India, for example, has a more diverse range of ecosystems at the ecosystem level thanks to its deserts, rain forests, mangroves, coral reefs, wetlands, estuaries, and alpine meadows. The species diversity has a latitudinal gradient (Tittensor *et al*., 2010).

Importance of Biodiversity

Protection of water resources: Natural vegetation cover helps in maintaining hydrological cycles, regulating and stabilizing water run-off and acting as a buffer against extreme events such as floods and droughts.

Pollution reduction: Plants absorb atmospheric gases, and ecosystems and ecological processes are crucial to maintaining the atmosphere's gaseous composition emit oxygen and carbon dioxide.

Certain ecosystems, particularly wetlands, have the capacity to decompose and absorb contaminants.

Climate stability: Vegetation influences climate at macro as well as micro levels. Cooling effect of vegetation is a common experience which makes living comfortably.

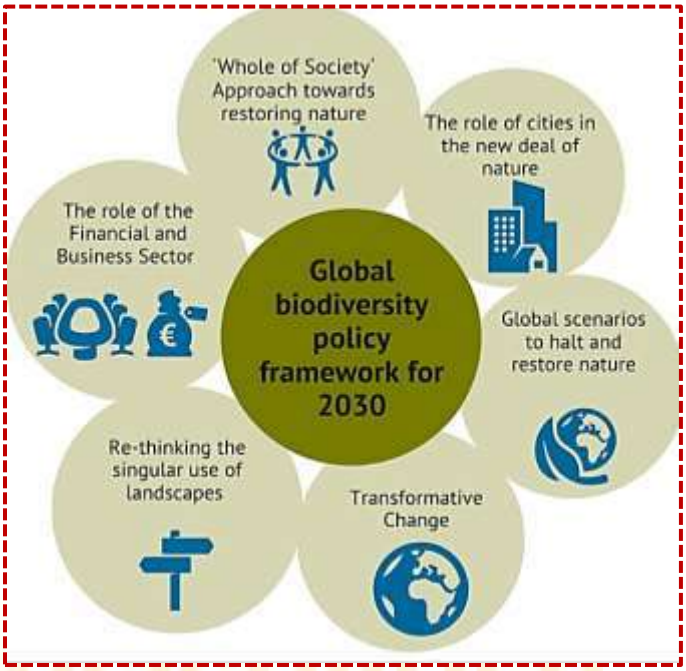
Soil protection: Biological diversity helps in the conservation of soil and retention of moisture and nutrients.

Nutrient storage and cycling: Ecosystem perform the vital function of recycling nutrients found in the atmosphere as well as in the soil. Plants are able to take up nutrients, and these nutrients are used by a wide range of life forms. Nutrients in the soil, in turn, are replenished by dead or waste matter which is transformed by micro-organisms.

Maintenance of ecological processes: Different species of birds and predators help to control insect pests, thus reduce the need and cost of artificial control measures.

India as a Mega Biodiversity Nation

India has a rich heritage of biodiversity, encompassing a wide spectrum of habitats from tropical rainforests to alpine vegetation, and from temperate forests to coastal wetlands. Almost all the biogeographical regions of the world are represented here in India. India is one of the 12 mega-diversity nations of the world. With a mere 2.4% of the total land area of the world, the known biodiversity of India contributes 8.22% of the known global biodiversity. India is one of the twelve mega-diversity nations of the world accounting for 7.31% of the global faunal and 10.88% of the global floral total species. Generally, biodiversity tends to cluster in hotspots (Myers *et al*., 2000). Some of the salient features of India's biodiversity are as under:



- ✓ India has two major realms called the Palaearctic and the Indo Malayan; and three biomes, namely the tropical humid forests, the tropical dry deciduous forests and the warm desert/ semi-deserts.
- ✓ India is one of the 12 centres of origin of cultivated plants.
- ✓ There are two hotspots that extend into India. There are the Western Ghats/ Sri Lanka and the Indo-Burma region (covering the Eastern Himalayas). Further these hotspots are included amongst the top eight most important or hottest hotspots.
- ✓ India has 26 recognized endemic centers that are home to nearly a third of all the flowering plants (angiosperms) identified and described to date.

- ✓ India has six Ramsar Wetlands. They are-Chilika lake, Harike lake, Loktak lake, Keoladeo national park, Wular lake, and Sambhar lake.
- ✓ India has 5 world heritage sites namely, Kaziranga National Park, Keolades Ghana National Park, Manas Wildlife Sanctuary, Nanda Devi National Park and Sundarban National Park.
- ✓ India has twelve biosphere reserves, namely Nilgiri, Nanda Devi, Nokrerk, Manas, Sunderbans, Gulf or Mannar, Great Nicobar, Similpal, Dibru-Saikhowa, Dehang Debang, Pachmarchi and Kanchanjanga.
- ✓ Further, amongst the protected areas, there are 88 national parks and 490 sanctuaries in India covering an area of 1.53 lakh km^2.

Conclusion

An area with a higher species abundance is thought to have a more stable ecology than one with a lower species abundance. By taking into account how dependent we are on the environment, we may further assert the need for biodiversity. In order to provide sustainable advantages for both the current and future generations, biodiversity conservation refers to the preservation, enhancement, and management of biodiversity. Human destruction of habitats has accelerated greatly in the latter half of the twentieth century. Natural habitats are often destroyed through human activity for the purpose of harvesting natural resources for industry production and urbanization. Clearing habitats for agriculture, for example, is the principal cause of habitat destruction. Other important causes of habitat destruction include mining, logging, and urban sprawl. Habitat destruction is currently ranked as the primary cause of species extinction worldwide.

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Vector Borne Diseases in India

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Introduction

The function of the arthropods is an intermediate or definitive host or reservoir to maintain and /or amplify the host like vertebrates. After pathogen dissemination, they may be refracted to infection and infectious (Reisen *et al*., 2010). According to vector definition they may be any arthropod (insect or arachnid) or animal which carries and transmits infectious pathogens and parasites directly or indirectly from an infected animal to a human or from an infected one infected person to another and causes diseases to the human beings. Vector- Borne diseases are described as many parasites and pathogens responsible for some of the most important diseases in humans, agriculture and in nature (Wilson *et al*., 2017). According to National vector borne disease control program, Ministry of government of India, there are various types of vector borne diseases like Malaria, Dengue, Japanese encephalitis, Kala-Azar, Lymphatic filariasis and Chikunguniya, etc. The epidemio-logical triangle of vector borne diseases includes host, pathogen and a transmitting agent as insect vector/rodent with interaction of environment. All the VBDs are climate sensitive as the pathogens have to complete part of their development in particular species of the insect vector that transmit them. As the insects are poikilothermic creatures, developmental period of their life cycle and development of parasite in their body are affected by climatic conditions. Because of the significance of malaria for worldwide public health, the influence of climatic conditions in its epidemiology has been thoroughly investigated. The lowest temperature necessary for *Plasmodium falciparum* parasites develop at 16.5-18°C, whereas *Plasmodium vivax* parasites develop at 14.5-16.5°C in anopheline mosquitoes. The sporogony of *P. vivax* can be finished in 55 days at 16°C, 7 days at 28°C, and 29 days at 18°C. Therefore, the distribution, level of endemicity, and epidemicity of diseases in a region are significantly influenced by the climate. Disease transmission occurs year-round in certain regions with the best rainfall and temperature, but it is seasonal and does not occur year-round in regions with colder months. The epidemiology of VBDs is intricate and multifaceted. The presence of the disease that is spread by a vector species does not always follow from its abundance. Vector-borne illness transmission is also influenced by develop-mental activities such as dam construction, enhanced

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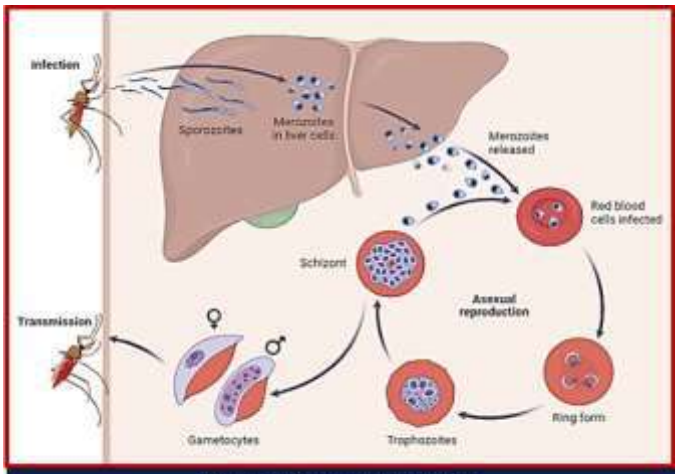
irrigation, agricultural practices, migration, health infrastructure, intervention measures, education, behavior, and economic conditions.

Different Vector Borne Diseases in India

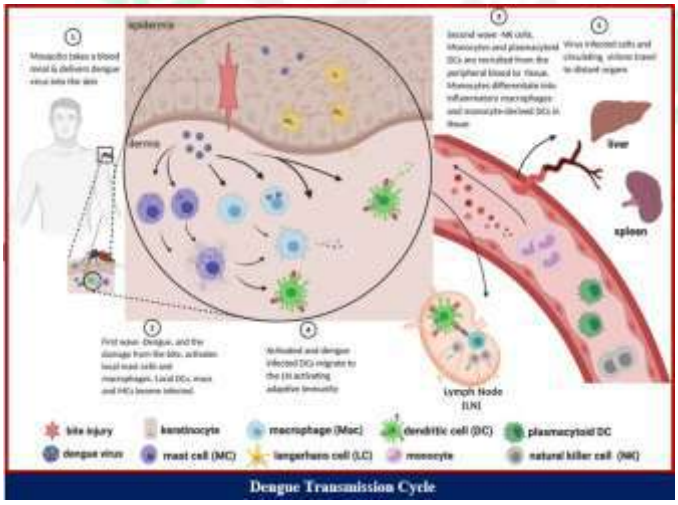
Malaria: In India, malaria is a serious health concern. The dynamics of malaria transmission are directly impacted by environmental factors. India is home to the majority of the six main species of malaria vectors: *Anopheles culicifacies, Anopheles stephensi, Anopheles fluviatilis, Anopheles sunda-icus, Anopheles minimus,* and *Anopheles dirus*. Temperature and mosquitoes interact with one another. Higher temperatures speed up the pace at which blood meal is digested, which accelerates ovarian development, egg laying, shortens the gonotropic cycle, and increases the frequency of feeding on hosts, all of which improve the likelihood of transmission. When the infected anopheline mosquito takes a blood meal, sporozoites are inoculated into the bloodstream. Within an hour sporozoites enter hepatocytes and begin to divide into exoerythrocyticmerozoites (tissue schizogony). For *P. vivax* and *P. ovale*, dormant forms called hypnozoites typically remain quiescent in the liver until a later time; P. falciparum does not produce hypnozoites. Once merozoites leave the liver, they invade erythrocytes and develop into early trophozoites, which are ring shaped, vacuolated and uninucleated. Once the parasite begins to divide, the trophozoites are called schizonts, consisting of many daughter merozoites (blood schizogony). Eventually, the infected erythrocytes are lysed by the merozoites, which subsequently invade other erythrocytes, starting a new cycle of schizogony. The duration of each cycle in *P. falciparum* is about 48 hours. In non-immune humans, the infection is amplified about 20-fold each cycle.



Malaria Transmission Cycle

Dengue: Variability in the climatic conditions also plays a significant role in the transmission of dengue as well. Dengue is also a major vector borne disease to the public globally. For the past 10 years, the number of dengue cases has gradually increased in India. It is caused by DENV, 1-4 serotypes and *Aedes aegypti* and *Aedes albopictus* are the major vectors for dengue in India. In India, the epidemiology of dengue was first reported in Madras (now Chennai) in 1780 and its first outbreak occurred in Calcutta (now Kolkata) in 1963. Since the 1990s, the epidemics of dengue have become more frequent and also spread to new regions such as Orissa, Arunachal Pradesh and Mizoram where it was unknown earlier. Since 2001, the number of dengue cases in India has increased. In addition to the rise in cases, its geographic spread has significantly changed. Dengue was once only found in cities, but it has since

begun to progressively expand to rural areas as well. The spread of dengue in India is caused by unplanned urbanization and changes in climatic factors. Additionally, insufficient vector control methods create favorable conditions for dengue transmission and associated vectors. The main host of dengue viruses, which are spread by Aedes mosquitoes, is humans. A mosquito contracts a virus when it feeds on the blood of an infected person. The virus travels from the mosquito's gut to tissues like the salivary gland in 8–10 days. It appears that the virus has no negative effects on mosquitoes. Humans and Aedes mosquitoes coexist in close proximity. Additionally, organ donation and contaminated blood products might spread dengue. Pregnancy can also result in vertical transmission from mother to kid (Tuiskunen Bäck and Lundkvist, 2013).



Dengue Transmission Cycle

Japanese encephalitis: The single-stranded RNA virus known as the Japanese encephalitis virus (JEV) is a member of the genus Flavivirus and family Flaviviridae. It is one of the most common types of viral encephalitis in the world, mostly affecting nearly three billion people in eastern and southern Asia. Although the majority of JE infections are asymptomatic, they can cause serious morbidity and mortality if they manifest as clinical disease. JE is thought to cause 50,000 cases and 15,000 fatalities yearly, although being underreported. Due to its high fatality rate and potential for epidemic spread, JE is a disease of public health relevance. Children between the ages of three and six experience age-specific attack rates in endemic areas. About one-third of patients pass away from the illness, and half of those who survive experience serious neuro-psychiatric after effects.

Kala-Azar: The family Trypanosomatidae (class Kinetoplastida) includes the genus Leishmania. The parasite is divided into two primary groups: the new world species, which are found in America, and the old world species, which are found in Europe, Africa, and Asia. Approximately 53 parasite species from various parts of the world have been described; of them, 31. There are 20 species that are harmful to humans and other species that parasitize mammals. Numerous eishmanial species that infect humans are zoonotic, meaning they have a wide range of domestic and wild mammal reservoir hosts; other parasite species are anthroponotic, meaning they can spread from person to person when the vector is present. Despite studies showing the presence of parasite or circulating antibodies against the parasite antigens in domestic and wild animals in India and the East, *Leishmania donovani* is typically regarded as an anthroponotic parasite. The kind of sickness that develops in a region is determined by the global

distribution of each Leishmania species. In South Asia and Africa, *L. donovani* produces visceral leishmaniasis, whereas *L. infantum* does the same. The life cycle of Leishmania species is heteroxenous.

Chikunguniya: The Chikungunya virus (CHIKV), an alphavirus carried by arthropods, is the cause of the acute febrile sickness known as chikungunya fever. Humans contract the virus mostly through the bite of an infected Aedes species mosquito. Aedes mosquitoes also spread the tropical virus that causes chikungunya. It is not well documented and rather rare. Africa, Asia, and islands in the Caribbean, Indian, and Pacific oceans have all reported cases of the illness. An acute illness with fever, skin rash, and debilitating joint pains that might persist for weeks are typical symptoms. The latter distinguishes chikungunya virus from dengue, which otherwise shares the same vectors, symptoms and geographical distribution. There is no cure or commercial vaccine for the disease. Most patients recover fully but, in some cases, joint pain may persist for several months or even years. As with dengue, the only method to reduce transmission of chikungunya virus is to control vector mosquitoes and protect against mosquitoes bites.

Conclusion

Vector-borne illnesses are a global public health concern, not just in Asia (India). The WHO and NVBDCP are conducting numerous disease control initiatives as a result of the outbreak of vector-borne illnesses such as malaria, dengue, chikungunya, JE, Kala-Azar, and filariasis. Certain diseases have specialized therapies, but for others, there is no vaccine. Controlling environmental and ecological issues is therefore essential. We can reduce the number of patients with vector-borne diseases by putting in place high-quality vaccine and immunization programs, altering agricultural methods, controlling vectors, and raising living standards. Vector control is one of the main tenets of VBD containment, and several techniques have been used for many years. These include biological control techniques like larvivorus fishes, environmental control and modification strategies including source reduction, and chemical insecticides used in indoor residual sprays, space sprays, fogging, treated bednets, and larvicides. However, a number of factors, including insecticide resistance, outdoor biting, behavioral changes in vectors for biting and resting, climate change, population movement, vector incursion to newer areas, and others, are making these treatments less and less effective.

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A Comprehensive Overview of Pests and Management Strategies for Muga Silkworms

Dinesh Daujirao Wanule

Introduction

The Muga silkworm (*Antheraea assamensis* Helfer) is a holometabolous, multivoltine, and oligophagous lepidopteran species of profound economic and cultural significance. As a poikilo-thermic organism, its growth and development are strongly modulated by abiotic factors such as temperature, humidity, rainfall, and photoperiod (Sarkar *et al.*, 2023). However, outdoor rearing exposes these silkworms to continual environmental fluctuations throughout the year, making them highly susceptible to pest infestations and disease outbreaks, which in turn reduce productivity.

State-wise Cultivation of Muga Silk in India

Muga silk production in India is almost entirely concentrated in Assam, with only small-scale contributions from other North-Eastern states such as Arunachal Pradesh, Manipur, Meghalaya, Mizoram, and Nagaland. These neighbouring states practice limited rearing, but their share of production remains negligible compared with Assam's dominance. As reported in the Central Silk Board Annual Report (2023-24), the country's total Muga silk output was 202 MT, with Assam accounting for virtually the entire figure (NEDFi, 2024a; NEDFi, 2024b; MoT, 2025). This confirms Assam's unique role as the principal centre of Muga culture in India.

Economic Importance and Foreign Exchange

Despite its relatively small contribution to India's overall silk production, Muga silk carries exceptional economic and cultural significance because of its natural golden lustre, heritage status, and premium market demand.

- ✓ India's silk and silk product exports were valued at US$ 244.27 million in FY 2024, while during FY 2025 (April-December) the sector had already earned US$ 215 million (IBEF, 2025; Indian Trade Portal, 2025).
- ✓ The earlier estimate of US$ 410.61 million in raw silk exports during 2021-22 represents the combined contribution of mulberry, tasar, eri, and Muga silk, with Muga representing only a small share by weight but commanding the highest unit price (MoT, 2022).
- ✓ The luxury status of Muga silk is reflected in its retail value. A traditional handwoven Muga saree often sells between ₹60,000 and ₹150,000, highlighting its global niche positioning and capacity to generate high returns despite low production volumes (Verma *et al.*, 2023).

Thus, while Muga silk production remains quantitatively limited, its premium pricing and cult-

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Table 1: Key Insect Pests and Predators of Muga Silkworm (*Antheraea assamensis*)

Common Name	Scientific Name	Order	Family
Uzifly	*Exorista sorbillans*	Diptera	Tachinidae
Apanteles	*Cotesia glomerata*	Hymenoptera	Braconidae
Red Ant	*Oecophylla smaragdina*	Hymenoptera	Formicidae
Canthecona	*Eocanthecona furcellata*	Hemiptera	Pentatomidae
Reduvid bug	*Sycanus collaris*	Hemiptera	Reduviidae
Wasp	*Vespa orientalis*	Hymenoptera	Vespidae
Praying Mantis	*Hierodula westwoodi*	Mantodea	Mantidae

ural heritage make it a disproportionately important contributor to foreign exchange earnings and rural livelihood security in Assam.

Ecological and Geographical Diversity of Pests in Muga Sericulture

The silkworms feed primarily on the foliage of Som (*Persea bombycina*) and Soalu (*Litsea monopetela*) (Kumar *et al*., 2002). Effective pest management strategies therefore demand a comprehensive understanding of the pest complex across diverse agro-climatic zones. Several studies have demonstrated that the incidence and diversity of insect pests vary geographically, with the pests associated with Muga rearing belonging to diverse families such as Tachnidae, Braconidae, Formicidae, Pentatomidae, Vespidae, and Mantidae (Singh and Das, 1993). These findings underscore the necessity for region-specific approaches to pest and predator management in order to safeguard this economically vital sericultural resource.

The Major Pest Complex in Muga Sericulture

A total of thirty-nine insect species belonging to twenty-five families have been documented as pests of the primary host plants of the Muga silkworm (*Antheraea assamensis*) as well as the silkworm itself at the Regional Muga Research Station (RMRS), Boko, Assam. Among these, the Uzi fly (*Exorista* spp.), a notorious endoparasitoid, is particularly destructive, causing mortality in silkworms during both larval and pupal stages. This parasitoid exhibits a remarkably broad host range and has been reported from ninety-five insect species worldwide, representing twenty families of Lepidoptera and one family of Hymenoptera, even in habitats where silkworm populations are absent.

Uzi Fly (*Exorista sorbillans*; Diptera: Tachinidae)

The Uzi fly (*Exorista sorbillans* Wiedemann) is regarded as one of the most destructive parasitoids in sericulture, particularly due to its endo-larval parasitic behaviour. It is responsible for serious economic losses, with infestations reducing cocoon yields by an estimated 10-20% each year (Kumar *et al.,* 2002; Rahmathulla, 2012). Although the pest can be observed throughout the year, its incidence is most pronounced during the monsoon and post-monsoon period from July to November (Gupta *et al.,* 2011). Infestation has a marked effect on cocoon quality; in heavily parasitized populations, nearly all cocoons become stained, whereas in healthy lots, the incidence of staining rarely exceeds 3-4% (Sarkar *et al.,* 2023). The fly exhibits a clear preference for silkworm larvae in the fourth and fifth instars, which are the most susceptible stages (Rao *et al*., 2004). Females oviposit on the intersegmental membranes

of the larval integument. After hatching, the maggots penetrate the host body and feed internally, particularly on the fat bodies and vital tissues. Following development, the larvae leave the host and pupate in the soil (Narayanaswamy and Devaiah, 2011). When parasitism occurs during early instars, the host dies before cocoon formation. In contrast, infestations at later stages allow cocoon spinning but result in structurally weak or stained cocoons that are unsuitable for reeling, thereby lowering their commercial value (Singh and Das, 1993; Rahmathulla, 2012).

Symptoms of Uzi Fly Infestation in Silkworms

Visible Indicators on Larvae

Oviposition scars: Adult females deposit eggs on the soft intersegmental membranes of silkworm larvae. Initially visible as small, raised, dark spots, these sites later develop into characteristic scars once the maggots penetrate the cuticle.

Stage vulnerability: Although attack may begin from the third instar, the fourth and fifth instars are the most susceptible. Infestation at this stage is particularly damaging as it coincides with the period just prior to cocoon formation.

Impact on Cocoons and Silk Yield

Emergence holes: Mature Uzi maggots, after completing their development inside the host, exit through the cocoon wall, creating distinct circular perforations. These exit holes are a diagnostic feature of infestation.

Inferior cocoon structure: Larvae that survive parasitism until spinning produce weak and poorly structured cocoons because of reduced vitality.

Reeling defects: Cocoons pierced by maggots lose filament continuity, rendering them unreelable and unsuitable for commercial silk extraction.

Mortality in Early Stages

Premature larval death: When infestation occurs in the third or early fourth instar, the silkworm seldom survives to spin. The developing parasitoid consumes the internal tissues, resulting in early mortality of the host.

Integrated Pest Management (IPM) for Uzi Fly (*Exorista sorbillans*)

The Uzi fly (*Exorista sorbillans* Wiedemann; Diptera: Tachinidae), sometimes referred to as *E. bombycis*, is a destructive parasitoid of silkworms, particularly *Bombyx mori* and *Antheraea assamensis* Effective management of this pest relies on an Integrated Pest Management (IPM) approach that combines cultural, mechanical, chemical, and biological control strategies to minimize damage while maintaining environmental sustainability (Kumar *et al.*, 2002; Rahmathulla, 2012).

Cultural and Mechanical Control

Rearing house sanitation: Regular cleaning of rearing rooms is essential to remove residual mulberry leaves, silkworm litter, and waste materials that may harbour Uzi fly pupae. Infested larvae and perforated cocoons must be collected and destroyed, preferably by deep burial or incineration (Narayanaswamy and Devaiah, 2011).

Physical exclusion: Preventing adult flies from accessing silkworms is the most reliable preventive

measure. Fine-mesh nylon or plastic "Uzi nets" should be installed on windows and ventilators. Establishing an ante-room or double-door entry system further reduces the risk of fly entry during routine handling. Destroying weak or perforated cocoons also prevents further maggot emergence (Gupta *et al*., 2011).

Trapping and Chemical Measures

Chemo-traps: Pheromone-based traps are widely employed to capture adult males, thereby disrupting mating and reducing overall fly populations. These traps are installed both inside and outside rearing facilities to maximize effectiveness (Rao *et al*., 2004).

Ovicidal dust (Uzi powder): This is a commercially available ovicidal formulation applied directly to silkworm larvae. It prevents egg hatching and maggot penetration. Recommended application is during the third instar (days 2, 4, and 5) and during the fifth instar (days 2, 4, and 6), at approximately 4-5 kg per 100 disease-free layings (DFLs). Application must be carried out with caution to avoid adverse effects on the host larvae (Rahmathulla, 2012).

Biological Control

Parasitoids: The pupal parasitoid *Nesolynx thymus* (Hymenoptera: Eulophidae) has proven highly effective in suppressing Uzi fly populations. These minute wasps parasitize Uzi pupae, preventing adult emergence. They are typically released during the fifth instar of the silkworm, ensuring overlap with Uzi fly pupal stages (Srinivasa and Govindan, 2002).

Predators: Natural predators such as red ants (*Oecophylla smaragdina*) and predatory wasps contribute to population suppression in outdoor rearing environments, although their use is less controllable in structured sericulture systems (Singh and Das, 1993).

In sericulture, the major parasitoid threat is the Uzi fly (*Exorista sorbillans* Wiedemann), which causes substantial economic losses in silk production. The Central Silk Board (CSB) of India recommends a comprehensive IPM package for its management:

Table 2: Integrated Pest Management (IPM) Strategies for Uzi Fly (*Exorista sorbillans*)

Management Method	Description / Key Practice
Physical exclusion	Install nylon Uzi nets on all windows and ventilators of rearing houses, and adopt ante-room/double-door entry systems to prevent fly entry.
Trapping	Deploy pheromone or chemo traps during the rearing cycle and maintain them after cocoon spinning to capture adult flies and reduce population pressure.
Biological control	Release the pupal parasitoid *Nesolynx thymus* at ~2 pouches per 100 disease-free layings (DFLs) during the fifth instar. Pouches are subsequently shifted to mounting halls and then to litter pits, ensuring parasitoid activity continues against residual Uzi pupae.
Sanitation	Maintain strict hygiene by removing rearing waste and perforated cocoons promptly. These should be destroyed by deep burial or burning to interrupt the Uzi fly life cycle, a critical measure mandated under CSB regulations.

This integrated framework combines mechanical, cultural, and biological tactics, and has been scientifically validated as the most effective means of minimizing Uzi fly damage while safeguarding silkworm health and cocoon yield.

Cotesia glomerata (Hymenoptera: Braconidae)

The braconid wasp *Cotesia glomerata* (formerly *Apanteles glomeratus*) is a well-studied gregarious endoparasitoid, widely recognized for its role in regulating populations of Pierid butterflies, particularly the large white (*Pieris brassicae*) and the cabbage white (*Pieris rapae*) (Harvey *et al*., 2010; Quicke, 2015). Adult females oviposit multiple eggs into the haemocoel of caterpillars, where the developing larvae consume host tissues internally. At maturity, parasitoid larvae exit the host and spin characteristic clusters of silken white cocoons, usually attached externally to the cuticle. This emergence and cocoon clustering are diagnostic features of parasitization (Godfray, 1994). As a gregarious species, dozens of individuals can develop from a single host larva, ultimately leading to host death. Although *C. glomerata* has occasionally been reported in association with non-Pierid hosts, including experimental infestations of silkworm larvae, it is not considered a significant pest in sericulture. Reports of 10-15% losses are more accurately attributed to specialized silkworm parasitoids such as the Uzi fly (*Exorista sorbillans*), rather than *C. glomerata* (Rahmathulla, 2012). Nonetheless, the species remains ecologically important as a natural biological control agent of Pierid pests in cruciferous crops.

Management of *Cotesia glomerata* (Hymenoptera: Braconidae)

The braconid wasp *Cotesia glomerata* (formerly *Apanteles glomeratus*) is a gregarious endoparasitoid widely recognized as a beneficial insect in agricultural ecosystems. It plays a critical role in the natural regulation of Pierid butterfly populations, particularly the large white (*Pieris brassicae*) and the cabbage white (*P. rapae*). As such, it is not a pest but an agent of biological control that should be conserved within cruciferous cropping systems. The Government of India's Integrated Pest Management (IPM) guidelines for cruciferous vegetables emphasise measures that protect and enhance *C. glomerata* populations. These include:

Selective pesticide use: Avoid broad-spectrum insecticides that harm parasitoids; prefer selective or biopesticide formulations.

Physical barriers: Use fine-mesh netting in nurseries to reduce butterfly oviposition.

Agro-ecological practices: Promote intercropping (e.g., nasturtium), provide bird perches, and release *Trichogramma* spp. for complementary egg-parasitism.

Conservation focus: Encourage field conditions that support *C. glomerata*, allowing it to naturally suppress Pierid caterpillar populations.

These measures are consistent with modern IPM principles that integrate natural enemies into sustainable pest management strategies.

Ants (*Hymenoptera: Formicidae*) as Predators of Muga Silkworms

Ants constitute one of the most persistent natural enemies of the Muga silkworm (*Antheraea assamensis* Helfer) under outdoor rearing conditions in Assam and adjoining North-East India. Several species, including the red weaver ant (*Oecophylla*

smaragdina), black garden ant (*Camponotus compressus*), and carpenter ants (*Camponotus* spp.), attack silkworm larvae in the field. Their predatory behaviour involves seizing young or mid-instar larvae with their mandibles, often carrying them back to nests, or immobilising larger larvae by biting appendages and body segments. Such attacks can lead to mortality or severe stress, ultimately reducing larval survival and cocoon yield. Seasonal surveys report that ant predation may account for 12-18% losses in Muga crops, particularly during the summer months when ant activity peaks (Sarmah *et al*., 2010; Subharani *et al.*, 2015).

Management Strategies (GOI/CSB-recommended)

To mitigate ant predation in Muga rearing, the Central Silk Board (CSB) and Regional Muga Research Station (RMRS, Boko) advise the following practices:

Field sanitation and nest destruction: Identify and remove ant nests on host plants before brushing larvae to prevent immediate predation during the rearing cycle.

Tree-trunk barriers: Apply sticky substances (e.g., grease bands, yellow sticky traps, or locally available adhesives) around host plant trunks to prevent ants from climbing and reaching silkworms.

Site rotation: Periodically shift outdoor rearing plots to new locations, thereby disrupting established ant colonies and reducing predation pressure over successive generations.

Integrated approach: Combine physical barriers with habitat management such as pruning lower branches or clearing weeds around host plants to reduce nesting sites and movement corridors for predatory ants. These strategies, when implemented collectively, can significantly minimise ant-induced mortality in Muga rearing and contribute to stable cocoon production in sericulture clusters of Assam.

Reduviid Bug (*Sycanus collaris*) (Hemiptera: Reduviidae)

The reduviid bug *Sycanus collaris* is a well-documented predator of the Muga silkworm (*Antheraea assamensis* Helfer) in Assam and adjoining regions. It attacks primarily early-instar larvae by piercing the integument with its elongated proboscis and sucking the haemolymph, which results in paralysis and eventual death of the host. Feeding by *S. collaris* can cause localized but significant larval mortality in outdoor rearing fields, adding to the cumulative losses caused by other predatory insects (Sarmah *et al*., 2010; Subharani *et al.*, 2015).

Management Strategies (GOI/CSB-recommended)

According to the Central Silk Board (CSB) and Regional Muga Research Station (RMRS, Boko), integrated approaches should be adopted to minimize predation by reduviid bugs:

Protective netting: Conduct rearing under nylon Uzi nets to physically exclude reduviid bugs and other predatory insects. This is one of the most reliable preventive measures.

Mechanical control: Manually collect and destroy

reduviid bugs observed on host plants or in rearing plots, especially during the vulnerable early instar stages of larvae.

Field sanitation: Clear weeds, shrubs, and alternate host vegetation around rearing plots to reduce hiding and breeding sites for reduviid bugs.

Rearing site selection and rotation: Choose rearing fields away from areas with dense vegetation or predator abundance; rotate sites seasonally to break predator populations.

Community-based monitoring: Encourage farmer groups to collectively monitor and suppress reduviid bug populations, as recommended in CSB's package of practices for Muga culture.

These practices, when followed in combination, reduce predation pressure and ensure safer outdoor rearing of Muga silkworms.

Predatory Stink Bug (*Eocanthecona furcellata*) (Hemiptera: Pentatomidae)

The predatory stink bug *Eocanthecona furcellata* Wolff is a hemipteran insect belonging to the family Pentatomidae. Although some pentatomids are phytophagous, *E. furcellata* is a well-known zoophagous predator that attacks a variety of soft-bodied insects, including lepidopteran larvae. In the context of Muga silkworm (*Antheraea assamensis* Helfer) culture, this predator poses a significant threat, particularly to early instar larvae. Using its elongated piercing-sucking mouthparts (proboscis), it punctures the body wall and feeds on larval haemolymph, resulting in paralysis or death of the host. Such predation contributes to notable larval losses in outdoor rearing systems (Singh *et al*., 2022; Sarmah *et al*., 2010).

Management of Predatory Stink Bug (*Eocanthecona furcellata*)

The predatory stink bug *Eocanthecona furcellata* poses a recurring challenge in outdoor Muga silkworm rearing. Its piercing-sucking feeding habit causes haemolymph loss in early-instar larvae, often resulting in paralysis or death. Since Muga silkworms are reared under open-field conditions in Assam, the Central Silk Board (CSB) and Regional Muga Research Station (RMRS, Boko) prescribe the following Integrated Pest Management (IPM) measures tailored for this predator:

Mechanical Control

Manual collection: Regular field monitoring and hand-picking of nymphs and adults from host plants are strongly advised. Captured insects should be destroyed immediately to prevent predation.

Egg mass destruction: Periodic examination of host plants for stink bug oothecae (egg masses) and their removal reduces population carry-over between rearing cycles.

Cultural and Habitat Management

Field sanitation: Removal of alternate host plants, weeds, and dense vegetation around rearing fields reduces shelter sites for stink bugs and lowers their prevalence.

Rearing site rotation: Changing rearing fields periodically disrupts stink bug colonisation and helps maintain lower predator pressure.

Physical Barriers

Protective netting: Covering host plants or rearing plots with nylon nets during the larval stages is an effective exclusion method, preventing entry of stink bugs and other predatory insects.

Biological Control

Parasitoid release: Egg parasitoids such as *Psix striaticeps* (Hymenoptera: Scelionidae) have been reported to parasitize stink bug eggs and significantly suppress their population (Singh *et al*., 2022).

Conservation of natural enemies: Avoidance of indiscriminate chemical use ensures survival of beneficial parasitoids and predators that naturally regulate stink bug populations.

Oriental Hornet (*Vespa orientalis*) (Hymenoptera : Vespidae)

The Oriental hornet, *Vespa orientalis* Linnaeus, is a large eusocial wasp belonging to the family Vespidae. It is one of the most destructive predators of the Muga silkworm (*Antheraea assamensis* Helfer) under outdoor rearing conditions in Assam. Both workers and queens attack silkworm larvae, especially during the later instars, by grasping them with their mandibles and feeding on soft tissues and haemolymph. Colonies established near rearing plots can inflict heavy larval mortality, leading to significant cocoon yield losses (Sarmah *et al*., 2010; Subharani *et al*., 2015).

Management Strategies (GOI/CSB-recommended, IPM approach)

The Central Silk Board (CSB) and Regional Muga Research Station (RMRS, Boko) prescribe the following Integrated Pest Management (IPM) practices against hornet predation in Muga rearing:

Mechanical Control

Destruction of nests: Locate and destroy hornet nests in and around rearing fields before the onset of brushing to prevent colony establishment near host plants.

Trapping of adults: Use locally designed baited traps (sugar solution, fermented jaggery, or meat baits) to capture adult hornets.

Physical Exclusion

Protective netting: Conduct silkworm rearing under nylon Uzi nets to physically prevent hornet entry and predation. Nets also offer protection against other flying predators like wasps and predatory bugs.

Cultural Practices

Field sanitation: Remove dried branches, hollow logs, and other potential nesting substrates around rearing sites that may facilitate hornet colony establishment.

Rearing site selection: Avoid rearing near forest edges or abandoned structures where hornet nesting is frequent.

Community-based Measures

Collective nest removal: Since hornet colonies can forage over long distances, coordinated community-level monitoring and nest destruction are more effective than isolated efforts by individual farmers.

Praying Mantids (*Mantodea: Mantidae*)

Praying mantids are large predatory insects characterized by their elongated bodies and raptorial forelegs, which are highly adapted for grasping and holding prey. Both nymphs and adults are voracious

predators in outdoor Muga silkworm (*Antheraea assamensis* Helfer) rearing fields. Early instar silkworm larvae are especially vulnerable, as mantid nymphs can easily seize and carry them away. Larger mantid adults are capable of subduing even late instar silkworm larvae, causing direct mortality and contributing to rearing losses (Sarmah *et al*., 2010; Subharani *et al*., 2015).

Management Strategies (GOI/CSB-recommended, IPM approach)

The Central Silk Board (CSB) and Regional Muga Research Station (RMRS, Boko) recommend adopting an Integrated Pest Management (IPM) framework to minimize mantid predation in Muga rearing:

Mechanical and Cultural Practices

Destruction of oothecae (egg masses): Regular inspection and removal of mantid oothecae from host plants and nearby vegetation before hatching is one of the most effective preventive measures.

Collection of adults and nymphs: Manual removal of mantids from rearing fields during larval brushing and throughout the rearing cycle reduces predation pressure.

Field sanitation: Clearing weeds, tall grasses, and unnecessary vegetation around host plants reduces potential hiding and breeding sites for mantids.

Site selection and rotation: Choosing rearing plots away from mantid-rich habitats and periodically rotating sites prevents predator build-up.

Physical Exclusion

Protective netting: Conducting rearing under nylon nets/Uzi nets serves as a multipurpose barrier against mantids, wasps, reduviid bugs, and Uzi flies.

Community-based IPM

Collective monitoring: Farmer groups are encouraged to monitor predator populations in a given cluster and apply mechanical control collectively for greater effectiveness (CSB, 2018).

Integration with other measures: Mantid management should be combined with general IPM practices (e.g., sanitation, predator removal, rearing under nets) that also address other Muga pests and parasitoids. These practices, when implemented systematically, lower the incidence of mantid predation and help stabilize Muga silkworm survival under outdoor rearing conditions.

Below is the list of references formatted in the Vancouver style, sorted alphabetically by the first author's last name.

Future Prospects in Pest Management for Muga Silkworms

The future of pest management in Muga sericulture will increasingly depend on the adoption of ecologically sustainable and technologically advanced strategies. Conventional practices alone may not be sufficient to counteract the growing pest pressure under climate variability and intensified outdoor rearing. Research priorities should therefore include the development of bio-rational pest control agents such as microbial biopesticides, pheromone-based formulations, and botanicals tailored for the unique agro-ecosystems of Assam. Another promising avenue lies in host plant improvement,

where enhancing the resistance of primary food plants such as *Persea bombycina* (Som) and *Litsea monopetala* (Soalu) could indirectly reduce pest infestations. In parallel, advances in silkworm genomics and molecular breeding may offer opportunities to enhance intrinsic pest tolerance in *Antheraea assamensis*. Digital agriculture will also play a pivotal role. Tools such as remote sensing, GIS-based habitat mapping, and precision pest monitoring systems can help forecast pest outbreaks and guide farmers in making evidence-based decisions. Ultimately, successful pest management will require a multi-stakeholder approach, involving collaboration between scientists, sericulturists, extension agencies, and policymakers to ensure that innovations are translated into practical and economically viable solutions for farmers.

Conclusion

The resilience of India's sericulture sector has historically depended on systematic annual planning and the integrated application of preventive and curative measures against pests and diseases. However, the diverse complex of insects that prey upon Muga silkworms and their host plants continues to impose serious limitations on silk productivity. The Muga silkworm (*Antheraea assamensis* Helfer), endemic to Assam and parts of Northeast India, is renowned worldwide for its naturally golden silk, a cultural and economic hallmark of the region. Yet, its outdoor rearing exposes it to seasonal environmental fluctuations and recurring insect pest infestations, which remain the primary cause of substantial crop losses. Strengthening pest management through innovative, sustainable, and region-specific approaches is therefore essential for safeguarding the heritage and future expansion of Muga sericulture.

Uncovering Health Benefits of Moringa

Gautam Gupta, Ashwini Abhijit Mankar and Ajay Baldaniya

Introduction

Products made from a variety of plants and herbs contain bioactive compounds and multi-purpose curative agents. Substances, are regarded as reasonably safe for ingestion. Roughly 70-80% of people worldwide, particularly in poor nations, use herbal medicine to prevent and treat illnesses, according to a research by the Food and Agriculture Organization (FAO) (Ekor, 2014), while roughly 25% of synthetic medications are made from medicinal plants. *Moringa oleifera* Lam is a perennial angiospermic plant that belongs to Moringaceae family commonly known as Drumstick tree, Ben tree, Horse-radish tree, Sohjna or Saijna. It is indigenous to South Asian countries mainly in India, Nepal, Bangladesh, Afghanistan, Sri Lanka and largely scattered in many tropical and subtropical countries around the around. Moringa oleifera is still considered as underutilized plants which have nutritional as well as medicinal values in its almost all parts like leaves, flowers, fruits (pods), seeds etc. Its gum (liquid sap), roots and bark also used traditionally as medicines. Due to its diversified nutritional benefits, medicinal properties as well as uses of commercial products of this plant, it is popularly known as 'Miracle Tree' which has potentialities in agriculture and industry as well. Moringa plants are highly nutritious that provides daily nutritional supplement boosting the immune system both uses in human and animals. Moringa leaves might be used to combat malnutrition, especially among infants and nursing mothers (Sobhy *et al*., 2015). India is the largest producer of moringa. Every part of the drumstick tree is enriched with varieties of ingredients that contribute to its magical health benefits. Moringa leaves are round shaped with wild leafy flavour and slight bitter taste. They are the significant source of calcium, iron, vitamin C, fibre, protein and β-carotene. Due to its antibacterial and anti-inflammatory action it can be used as a treating agent for diarrhoea, urinary disorder and gastric ulcer. Moringa leaves can successfully purify blood along with lowering of blood glucose and cholesterol level. In addition to its antioxidant qualities, moringa has a high protein level that includes all of the essential amino acids and a micronutrient composition that suggests it might be utilized as food. Intercropping is an option with

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many fruits and vegetables crop species to boost socioeconomic status of the rural population. Because they include higher levels of ascorbic acid, flavonoids, phenolics, carotenoids, glycosides, glucosinolates, and other compounds, it is clear that leaves and immature pods function as natural antioxidants. Alkaloids including moringine and moringinine, which function as cardiac and circulatory stimulants, antiulcer, and anti-inflammatory medicines, are also abundant in stem bark and roots (Adeyemi and Elebiyo, 2014).

Table 1: Ethnomedicinal and pharmacological uses of different parts of *Moringa oleifera* plants

Traditional uses	Plant part used
Used for prevention and treatment of several diseases like gastric ulcer, hay fever, fatigue, skin diseases and bronchitis, psychosis, eye diseases, fever and as an aphrodisiac in the Unani and Ayurvedic systems of medicine.	Different parts
Act as cardiac and circulatory stimulants, antipyretic, antiepileptic; possess antitumor, anti- inflammatory, antiulcer.	Leaves, roots, seed, bark, fruit, flowers and immature pods.
Used for the treatment of respiratory, gastrointestinal, inflammatory, cardiac, nutritional and skin diseases.	Different parts
Used for the treatment of asthma, epilepsy, eye and skin diseases, fever, headache, hemorrhoids, anti-helminths, kidney stones and arthritis.	Different parts
Used to treat arthritis, pain in joints, head, and stomach, and ears, act as a cardiac and circulatory stimulant, to treat colds, fever, kidney and liver problems.	Leaves, stems and roots
Used for treatment of fever (typhiod, malaria), ear and eye infections, skin diseases, common cold, diarrhea, blood sugar and blood pressure.	Leaves, stems and roots

Health benefits of Moringa

Constipation and Digestive Strengthening: Constipation can be relieved by consuming a drumstick seed powder with lukewarm water. Because of their high fiber content, these seeds help the body rid itself of toxins. By controlling the liver's bile juice release, they also lower blood and stomach acidity levels and support a healthy digestive tract.

Panacea for Blood Sugar and Diabetes Patients: Abundant amount of zinc is found in the seeds which prevents the sugar level from increasing in the blood. Drumstick seeds are like a lifesaver for diabetic patients because its consumption is extremely beneficial for both type-1 (insulin non-production) and type-2 (insulin resistance) diabetic patients.

Formation of Heart Tissue and Support to Heart Health: Drumstick seeds reduce the presence of oxidized lipids in the body, thereby protecting heart tissues from structural damage. They also regulate blood circulation in the arteries, lower LDL (Low-Density Lipoprotein) or bad cholesterol levels, and increase HDL (High Density Lipoprotein) or good cholesterol levels. This combination reduces the risk of heart attacks. Using seed-derived powder can provide relief from high blood pressure (Saa *et al*., 2019).

Pain Relief and Cancer Prevention: Drumstick seeds are rich in calcium, which contributes to strong bones. They possess anti-analgesic properties, offering relief from bone-related pain and joint pain

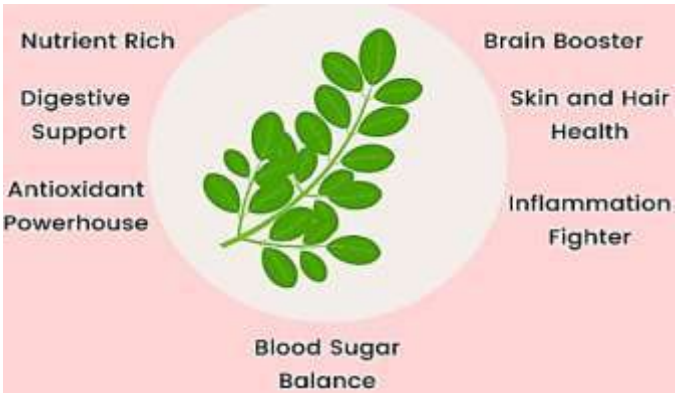
when used as massage oil. Additionally, these seeds contain glucosinolates, which are known for their ability to combat cancer-causing cells. Consumption of drumstick seeds can thus reduce the risk of developing cancer.

Pain Relief and Cancer: Calcium, which is abundant in moringa seeds, strengthens bones and eases discomfort associated with them. They reduce joint discomfort because of their analgesic qualities. The seeds' glucosinolate content lowers the risk of cancer by assisting in the destruction of cells that cause it. Therefore, eating Moringa seeds can reduce the risk of getting cancer.

Improvement in Immune System: While Moringa seeds indeed offer numerous medicinal benefits, it's essential to note that prolonged and unrestricted use can lead to certain physical issues, such as stomach irritation and increased menstrual flow in women. Women should avoid consuming seeds during their menstrual periods. Consumption of seeds during menstruation can lead to excessive blood flow and skin irritations. Therefore, it is advisable to consume them with caution and complete knowledge.

Nutritive Properties of Moringa

Every part of *M. oleifera* is a storehouse of important nutrients and anti-nutrients. The leaves of *M. oleifera* are rich in minerals like calcium, potassium, zinc, magnesium, iron and copper. Vitamin like beta-carotene of vitamin-A, vitamin-B, pyridoxine and nicotinic acid are also available. Moringa leaves also have a low calorific value and can be used in the diet of the obese. The pods are fibrous and are valuable to treat digestive problems and thwart colon cancer.



Industrial Potential of Moringa Seeds

Ben Oil Production: Moringa seeds yield precious oil known as Ben oil. Extracted through high-pressure cold press methods, this oil is highly regarded for its diverse uses. Packed with vitamins, amino acids, oleic acid, tocopherols, and sterols, it is prized for its therapeutic properties. Ben oil is often employed in skincare products to address various skin conditions and boost immune function. Moreover, it is an ally in promoting hair growth and development.

Bio-Diesel Production: Bio-diesel, also referred to as 'organic' diesel, serves as a sustainable alternative fuel source. Typically derived from plant oils, animal fats, waste oil, and leftover cooking oil, bio-diesel can be produced via a process called transester-ification. The beauty of using bio diesel lies in its compatibility with standard vehicle engines, requiring no intricate modifications. This makes it a highly suitable and convenient choice for powering agricultural equipment (Azad *et al*., 2015).

Flour Production Supplementation: A valuable dietary supplement and a potent remedy for child-

hood malnutrition, flour made from the seeds of the drumstick tree successfully resolves nutritional deficits due to its high content of vital components.

Facial Skincare: The oil derived from the drumstick tree, often referred to as Ben oil, is a prized ingredient for facial care. Its natural properties make it an excellent choice to reduce or eliminate facial blemishes, spots, and wrinkles. Additionally, it acts as a potent shield against free radicals, contributing to radiant and youthful-looking skin.

Scar Reduction: Drumstick tree oil is rich in collagen protein, a vital component that enhances skin health. This protein assists in reducing the appearance of scars on the skin, promoting a smoother complexion.

Purification of Water Using Seeds: Seeds of the drumstick tree are also used to purify water. Thus, it is straightforward to make dirty water or contaminated water clean and drinkable by using these seeds. Before starting the purification process, the mature pods are left on the tree for some time to dry. Once the pods are dry, they are collected from the tree. The seeds are separated from the pods before the purification process. The seeds are powdered, and a paste is made by mixing a small amount of the powder with water. Typically, it is stirred for about 10-15 minutes. After stirring, the paste is left undisturbed for about 2 hours, allowing impurities to settle at the bottom. The purified water is then carefully collected, leaving the sediment behind.

Conclusion

Moringa oleifera Lam. is a 'miracle plant' as its different parts contains important phytochemicals uses as nutritional supplement and traditional folk medicines. Moringa seeds represent a sustainable solution for health and commerce, addressing nutrition and health challenges while offering economic opportunities to individuals and communities. These plants have high medicinal and therapeutic properties as well as have an enormous nutritional benefit that provides future development in the arena of medical, socioeconomic, agricultural, industrial, commercial (cosmetics and water purifier), nutraceutical and pharmacological etc. Moreover, further researches are needed for optimum production of these crops, identification and isolation of phytochemicals for the diversified utilization of humankind and animals.

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Nettle Tea: An Herbal Elixir for Health and Wellness

Gautam Gupta and Ajay Baldaniya

Introduction

The Stinging nettle (*Urtica dioica* L.) has been used as a wild vegetable for centuries (Uprety *et al*., 2012). It is a perennial herbaceous plant with spiny leaves, belonging to the nettle family (Urticaceae). While stinging nettle can be found almost anywhere, it is most common in Europe, North America, North Africa, and parts of Asia. It can be found in the wild in the hills and mountains of Nepal. Nepali edible names includes nettle Sisnu, Sishnu, Lekali sishnu, Thulo sishnu, Ghario sishnu, Bhangresishnuor Patle sishnu. The plant is widely cooked in areas where vegetables are scarce. The use of stinging nettle slurry as a fertilizer in organic farming for horticultural crops is becoming more common in Spain, according to many ethnobotanical studies. It can be used as a blood-nourishing tonic and as a vegetable, tea, and juice, mostly for rhinitis. Nettle's ability to be used for a variety of reasons, including food, fodder, medicine, cosmetics, biodynamic agriculture, and textile production, is one of its key characteristics. Young leaves can be dried for use in the winter and added to soups when cooked as a potherb (Singh and Kali, 2019). Modern research has justified the use of *U. dioca* in traditional medicine and has also proved that its extracts have natriuretic, diuretic and hypotensive effects. Recently, it was discovered that the leaf extracts from *U. dioica* have an anti-inflamma tory effect due to its inhibitory effect on NF-κB activation, a family of transcription factors which are critical for the inducible expression of many genes involved in inflamma tory responses. Nutritional interest for leaves from wild species was initially on the pro-vitamin A carotenoids, as they provide the major source of dietary pro-vitamin A in several countries (Tahri *et al*., 2000). With their many health advantages, herbal preparations particularly herbal teas have long been a mainstay of traditional medicine. Their appeal is influenced by how simple they are to prepare and consume. Nettle tea is a powerful herbal tea among the many types used for different purposes. Herbal concoction with medicinal qualities. This tea, which comes from the stinging nettle plant (*Urtica* sp.), is well-liked for its therapeutic and nutritional properties. Because of their stinging hairs, nettles are frequently thought of as troublesome weeds, but they also contain a variety of minerals and bioactive chemicals that are good for human health.

Nutritional Status of Nettle Plant: The two main components of *U. dioica* that contribute to its

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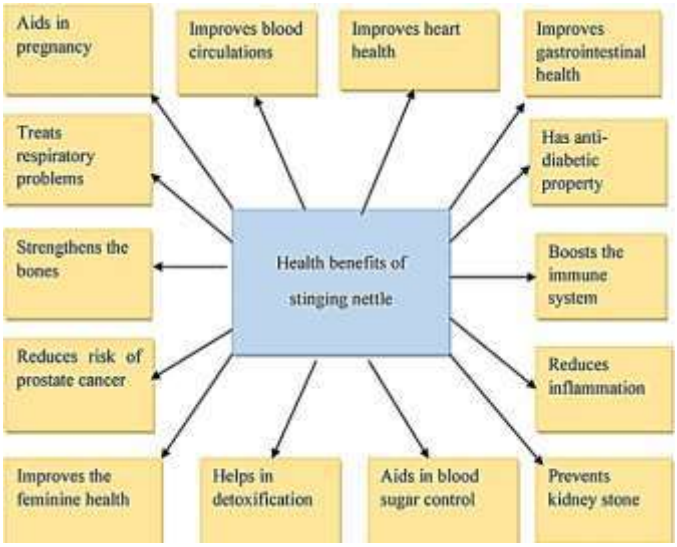
nutritional value are its seeds and green leaves. Because they are a rich source of polysaccharides, vitamins (β-carotene), iron, potassium, manganese, calcium protein, silicon, phosphate, and vitamin C, young leaves and shoots are utilized as food. Despite having a low saturated fat content, its leaves are rich in important fatty acids like α-linolenic and linoleic acid, essential amino acids, carbohydrates, and carotenoids including lutein, β-carotene, and omega-6 fatty acids. Because of their rich nutritional content, leaves are used in human consumption to create soups, strengthen the body, and naturally flavor food (Wetherilt and Kavalali, 2003). Nettle can be an important source of dietary fiber due to high pectin content. Caffeyl-malic acid 1.6 %, chlorogenic acid 0.5 %, small amounts of neochlorogenic and free caffeic acids were detected in *U. dioica* leaf extract analysed by Gel-exclusion HPLC (Obertreies *et al*., 1996).

Preparation of Nettle Tea: The materials needed for preparing nettle tea include 1-2 teaspoons of dried nettle leaves per cup of water, 1 cup of filtered water per serving, optional sweeteners such as honey or stevia, optional flavor enhancers like lemon or ginger, and a tea strainer or infuser.

Harvesting of Leaves: The tiny trichomes that cover nettle leaves hurt the skin because they contain secondary metabolites including acetylcholine and histamine. Thus, to prevent skin discomfort during harvesting, wear gloves. Because they have a higher concentration of health-promoting chemicals, tender leaves are favored when making tea. To get rid of dirt and contaminants, give the leaves a thorough rinse under running water.



Boiling Water: Heat a cup of filtered water until it reaches a near-boiling temperature (around 90-95°C or 194°F).

Infusion Process: Add the fresh or dried nettle leaves to a teapot or cup. Pour the hot water over the leaves and let it steep for 5-10 minutes.

Straining and Serving: Use a tea strainer or infuser to strain the tea. To improve the flavor, you can add alternative seasonings like ginger, lemon, or honey.

Benefits of Nettle Tea: The many health advantages of nettle tea are attributed to its abundance of bioactive chemicals, which are extracted from the plant's leaves. Nettle leaves and roots include vital vitamins including A, C, K, and B vitamins, which help metabolism, skin health, and immune function, according to the table supplied. The minerals-calcium, iron, magnesium, phosphorus, potassium, and sodium help maintain healthy bones, muscles, and general health. Nettle tea also contains all of the key amino acids required for body processes, as well as healthy fats like oleic and linoleic acids.

The presence of polyphenols, such as kaempferol, quercetin, and caffeic acid, enhances its antioxidant and anti-inflammatory properties. Furthermore, pigments like beta-carotene and lutein contribute to eye health and cellular protection. Regular consumption of nettle tea may support detoxification, cardiovascular health, and immune defense, making it a valuable herbal infusion. (Said *et al*., 2015). Here are some of its notable benefits:

Anti-Inflammatory Properties: Nettle tea is known for its potent anti-inflammatory effects, making it beneficial for conditions like arthritis and other inflammatory disorders.

Boosts Immunity: The high vitamin C and antioxidant content help strengthen the immune system, protecting the body against infections and diseases.

Rich in Nutrients: Vitamins A, C, K, and numerous B-complex vitamins are found in nettle leaves. Iron, calcium, magnesium, and potassium, which are critical for healthy bones and metabolic processes, are also abundant in them.

Regulates Blood Sugar Levels: Some studies suggest that nettle tea may help regulate blood sugar levels, making it a potential natural remedy for managing diabetes.

Supports Digestive Health: Nettle tea aids digestion by promoting gut health and relieving bloating, constipation, and other digestive issues.

Improves Skin and Hair Health: The high antioxidant and mineral content in nettle tea can promote clearer skin and healthier hair by reducing acne, dandruff, and hair fall.

Detoxification and Kidney Health: Nettle tea acts as a natural diuretic, helping the body flush out toxins and support kidney function.

Conclusion

An ancient herbal treatment, nettle tea has several health advantages, including better digestion, cleansing, and immune support. Its antioxidant and anti-inflammatory qualities, along with its rich nutritional profile, make it a useful supplement to a healthy way of living. Nettle tea is positioned to become a popular wellness beverage that connects ancient herbal therapy with contemporary health trends as research continues to reveal its full potential.

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Role of Arbuscular Mycorrhizal Fungi (AMF) in Sustainable Agriculture

Laxmi G. Hadimani, S. Syam Prasad and Ajay Baldaniya

Introduction

The human population has doubled during the last forty years, and food production has also doubled at the same time. A major factor in the significant rise in supplying and meeting the demand for food has been plant nutrition. The usage of commercially produced fertilizers has enabled an increase in crop productivity. Phosphorus (P) fertilizer consumption has more than quadrupled, while nitrogenous (N) fertilizer consumption has nearly tripled. These advancements have been made possible at comparatively low costs by the massive expansion of N and P fertilizers as well as the introduction of extremely productive agricultural techniques. However, the increased use of fertilizers and extremely productive systems has also led to environmental issues such air pollution, decreased biodiversity, and suppressed ecosystem function, as well as degradation of soil quality, surface water, and ground water. Increased nutrition availability may cause direct or indirect environmental contamination. Directly, leaching, volatilization, acidification, and denitrification can be caused by improper application, excessive fertilizer use, or improper fertilizer management. Airborne carbon dioxide and nitrogen pollution are indirectly caused by the manufacture of fertilizer (using fossil fuels in the Haber-Bosch process) and its transportation (using fossil fuels), which will ultimately be deposited into terrestrial ecosystems. Bio-fertilizers are the organic substances which make use of microorganisms to increase the fertility of soil. These fertilizers are not harmful to crops or other plants like the chemical fertilizers. They are actually taken from the animal wastes along with the microbial mixtures. Micro-organisms are used to increase the level of nutrients in the plants. They let the plants grow in a healthy environment. They are also environment friendly and do not cause the pollution of any sort. Use of bio fertilizers in the soil, makes the plants healthy as well as protect them from getting any diseases. The main sources of bio- fertilizers are bacteria, fungi, cyanobacteria, etc. Such bio-fertilizers are cultured and are used for inoculating seed or soil or both under ideal conditions to increase the availability of plant nutrients. Among this mycorrhiza is an important one in agriculture field for the cultivation of many crops. Soil micro-organisms such as arbuscular mycorrhizal fungi (AMF or AM fungi) represent a key link between plants and soil mineral nutrients.

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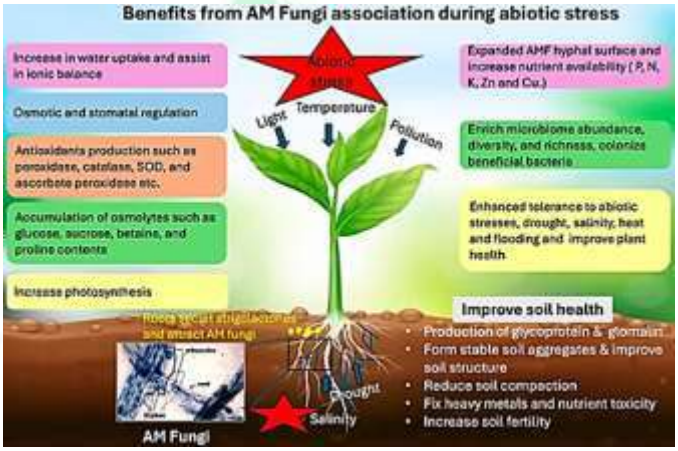
Thus, they are collecting growing interest as natural fertilizers. AMF are obligate symbionts, belonging to the phylum Glomeromycota (Schubler *et al*., 2001), which form mutualistic symbioses with about 80% of land plant species, including several agricultural crops. They provide the host plant with mineral nutrients and water, in exchange for photosynthetic products. The AMF mycelium that emerges from the root system can acquire nutrients from soil volumes that are inaccessible to roots (Smith *et al*., 2000). Then, within the roots, the plant-fungus interaction facilitates the exchange of minerals and carbohydrates. The term "Mycorrhiza" was coined by Frank (1885) who was fairly certain that these symbiotic plant-fungus associations were required for the nutrition of both partners. According to Brundrett (2004) mycorrhizas occur in a specialized plant organ where intimate contact results from synchronized plant-fungus development.

Contribution of AM Fungi in Agroecosystem Sustainability: An agroecosystem is a complex, interconnected network of biotic and abiotic com ponents within a defined agricultural area. A sustainable agroecosystem maintains long-term productivity by balancing resource conservation, economic feasibility, social acceptance and environmental integrity. The symbiotic association between the host plants and AM fungi is nature's gift for maintaining a sustainable agroecosystem in today's dynamic environment (Begum *et al*., 2019). One of the primary advantages of mycorrhizal associations is the increased absorptive surface area provided by the fungal hyphae. This extensive network of fungal filaments allows host plants to access a larger volume of soil and, consequently, a greater pool of nutrients. As a result, plants colonized by AM fungi exhibit improved nutrient uptake compared to their non-mycorrhizal counterparts. In addition to enhancing nutrient acquisition, AM fungi confer a higher tolerance to various environmental stressors. These fungi have been found to protect host plants from the detrimental effects of toxic metals, root pathogens, drought, salinity, elevated soil temperatures, unfavorable pH conditions, and transplantation shock.

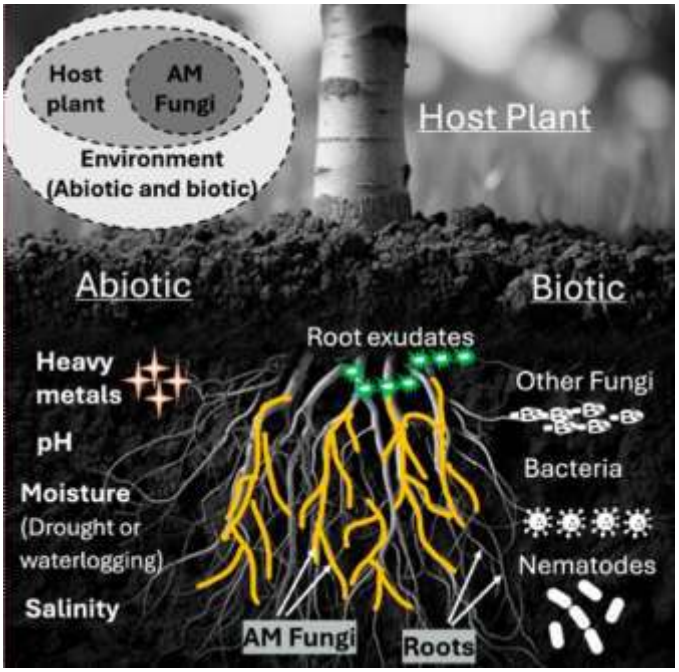


Maintaining Soil Health and Nutrient Cycling: Numerous nutrients, including both macro and micronutrients, can be absorbed by arbuscular mycorrhizal fungus. Because they can create enzymes like phosphatase, which increase the solubility of P and make it more available for plant uptake, they are very effective at absorbing P when compared to other nutrients. Interest in the commercial development of AM fungal inoculants has grown due to the potential of AM fungus to maintain soil health while supplying host plants with vital nutrients. Most plants' roots naturally contain

arbuscular mycorrhizal fungi, which have special skills to help plants absorb nutrients and cope with stress. Arbuscular mycorrhizal fungi, being a natural root symbiont, provide host plants easy access to various inorganic nutrients like N and P and have been found to increase the phytoavailability of micronutrients like Zn and Cu, allowing for efficient nutrient cycling between plants and microbes. Arbuscular mycorrhizal fungi can improve soil structure by creating stable aggregates. Stable soil aggregates are formed through the deposition of glycoprotein and glomalin on hyphal walls and surrounding soil. Glomalin works as a hydrophobic adhesive, preventing macroaggregate rupture during drying and wetting by reducing water transport into the pores of the aggregate structure. AM fungi create solid soil aggregates, which are the foundation of soil structure.

Transferring Resources within Agroecosystems: In intercropping systems, mycelial networks of AM fungi can facilitate the nutrient distribution between crop species, alleviating nutrient deficiencies in one crop while improving nutrient use efficiency across the intercropping system. Arbuscular mycorrhizal fungal inoculation has been found to enhance soybean plants' N fixation efficiency and facilitate the transfer of fixed N from soybean to maize in intercropping systems, ultimately leading to increased yields. This finding highlights the potential of AM fungi to optimize nutrient sharing and productivity in mixed cropping scenarios.

Mitigate Environmental Stresses: By creating stable soil aggregates, arbuscular mycorrhizal fungi also enhance the structure of the soil. Glycoprotein and glomalin are produced and deposited on the hyphal walls and neighboring soils as part of the process of creating stable soil aggregates. Glomalin functions as a hydrophobic adhesive, reducing the flow of water into the aggregate structure's pores and preventing macroaggregate rupture during drying and wetting events. In this manner, AM fungi create solid soil aggregates, which serve as the foundation for soil structure.



Maintaining Biodiversity: Biodiversity is crucial to the operation of agroecosystems. Numerous soil species found in roots, the rhizosphere, and bulk soil interact with arbuscular mycorrhizal fungus. The composition and abundance of the soil microbial population are greatly impacted by the presence of AM fungi. This effect is ascribed to changes in the exudates that the fungi and plant roots emit. A unique environment that promotes the growth and activity of

particular microbial populations while possibly suppressing others is created by the variations in the chemical content and quantity of the exudates. Arbuscular mycorrhizal fungi aided in the growth of *P. chlororaphis*, a helpful bacterium. They improved the germination of *T. harzianum* conidia, a fungus that is well-known for its ability to inhibit disease and promote plant development.

Challenges of AM Fungi in Maintaining Soil Health and Sustainable Agroecosystem: By developing symbiotic relationships with plant roots, increasing plant nutrient uptake, and boosting soil structure, arbuscular mycorrhizal fungi serve a critical role in preserving soil health and a sustainable agroecosystem. However, there are a number of obstacles to preserving the wellbeing and functionality of AM fungus. Mycorrhizal numbers and variety can be greatly impacted by intensive agricultural techniques such severe tillage, ongoing monoculture, and excessive use of chemical fertilizers. Heavy tillage fragments the vital hyphal networks that AM fungi depend on to support plant health and nutrient uptake, thus diminishing the symbiotic advantages they offer to crops that follow. The breaking apart of these networks by tillage impedes the mycorrhizae's functionality and impacts the broader soil ecosystem, reducing soil organic matter and disrupting essential nutrient cycling processes. These changes are detrimental to soil health and development, impairing the soil's ability to support robust plant growth and maintain ecological balance. The wide spread application of chemical fertilizers and pesticides in traditional farming practices has detrimental impacts on the populations and functions of AM fungi. Additionally, the use of pesticides and herbicides can disrupt the composition of soil microbial communities, posing a risk to the advantageous AM fungi.

Conclusion

When the soil's productive potential is maintained with the least amount of energy and resources while the environment is not harmed, a sustainable plant ecosystem is created. It can be obtained via the plants' effective use of nutrients, which is made possible by the AM fungi's symbiotic relationship. Additionally, these fungi aid in the formation of soil structures that lessen erosion and enhance water retention. Glomalin, a material they manufacture, is what holds soil particles together to create aggregates. These aggregates promote strong plant growth by retaining water and nutrients.

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Flowers: Precious Food and Medicine Resources

Mahima Sharma, Meenakshi Basoli and Rakesh Kumar

Introduction

The traditional primary health care system in India is embodied in a 'people's health culture'. This culture is based on very effective and sound, region-specific health practices involving 8,000 species of plants across the country where flowers play a prominent role among them. For several centuries medical practitioners have long been acknowledged the therapeutic properties of certain flowers. Flowers are matchless ornaments to the nature Queen. They are not only a source of beauty and delicacy but also fountain heads of health and joy. Flowers have been a vital part of society from the beginning of time. Because of their beauty, they are used as ornaments in a variety of settings, including pots, gardens, landscaping, and containers filled with cut flowers. Ornamental plants, which are grown especially for their eye-catching appearance, unique foliage, and subtle scent, bring character and appeal to any setting. Beyond just being aesthetically pleasing, flowers have long served as emotional symbols, being used in religious ceremonies, celebrations, and professions of love and grief. They also have positive effects on mental and emotional health (Fernandes *et al*., 2019). In recent years, the market for edible flowers has experienced remarkable growth. This phenomenon can be attributed to several reasons, including the increasing availability of information on their nutritional value and bioactive potential. The possible health advantages of particular secondary metabolites as well as other substances frequently present in flowers, such as carotenoids, phenolic compounds, vitamins C and E, saponins, or phyto-sterols, have also drawn more attention. The various colors of flowers are caused by carotenoids and phenolic chemicals, which are also notable for their health benefits and adaptability in agri-food and medical uses. Flowers are used in gastronomy for their pigments (such as carotenoids, flavonoids, and betalains), which improve the appearance of dishes, and for their characteristic flavours and odours, which make them an alternative food source. Some societies, such as Asian, Greek, Ancient Roman, French, and Italian, have a long-standing tradition of eating flowers. However, for a flower to be edible, it must not contain dangerous levels of toxic compounds that could affect the health of those who consume it (Alasalvar *et al*., 2013). On the other hand, the consumption of parts of plants is typical in traditional medicine, mainly in medicinal infusions

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Table 1: Some edible flowers with their uses

Common name	Botanical name	Uses
Pot marigold	*Calendula officinalis*	The petals are for edible decorative purposes; an alternative for saffron.
Tea Plant	*Camellia sinensis*	As vegetables in the meal.
Butterfly Pea	*Clitoria ternatea*	The petal used as a colorants.
Rose	*Rosa chinensis*	In fruit preserves and infusions.
Garden nasturtium	*Tropaeolum majus*	Ingredient in salad, drinks, and meals.
Jasmine	*Jasminum sambac*	In infusions and porridge
Roselle	*Hibiscus sabdariffa*	Ingredient in jams, fermented drinks, herbal drinks, cakes, chocolates, etc.
Bauhinia	*Bauhinia variegata*	Flowers and buds used as vegetables and pickles.
Red silk cotton	*Bombax ceiba*	Buds and flowers are cooked and pickled.
Palash	*Butea monosperma*	Flowers are used along with milk with sugar to make coolant drink.
Butter tree	*Madhuca longifolia*	Eaten raw, and used in local drinks. Sun-dried flowers are used as a sweetener.

Table 2: Details of flowers used in various systems of Indian Medicine

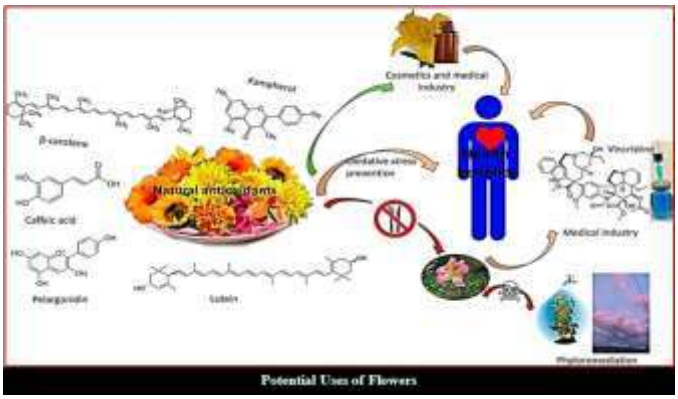
Botanical name	Flower description	Chemical constituents	Medicinal uses
Abutilon indicum	Flowers yellow and Solitary	Luteolin, chrysoeriol, luteolin	Disorders of nervous system, pain due to vata, internal injury of chest, Piles, ulcers, cough, skin diseases, leucorrhoea, jaundice, aphrodisiac
Adhatoda zeylanica	Flowers large, white with red or yellow spot at throat.	Luteolin, quercetin, kaempferol, alpfa-amyrin and alpfasitostero	Bronchial asthma, haemorrhage, wasting diseases, fever, delirium, skin diseasepiles, vomiting
Anthocephalous cadamba	Flowers are rounded crown, bears drooping branches and yellow flowers in globose heads.	Triterpenes, triterpenoid glycoside, flavonoid	It induces lactation
Cassia alata	Flowers large, yellow	Triterpenoid glycoside, flavonoid, Saponins, Tannins	Strong decoctions good for eczema, herpes and a lotion for ringworm, extracts used internally in cases of bronchitis
Chrysanthemum indicum	These dramatic flowers come in a wide range of colors, including red, orange, yellow, pink, white, and purple	Azulene and alpfa-3 carene, sesquiterpene ketodiol, indiculmenone	Juice or infusion of flowers is employed in vertigo, fever, headache, ophthalmia, xerophthalmia, hypertension, furunculosis and phlegm.
Crocus sativus	Flowers solitary or clustered, narrowly sessile, stamens 3 eared, basifixed blue, scented, appearing with leaves, throat of perianth bearded, anthers yellow.	Safranul, isophorene, glucoside, corcin, crocetin, picrocrocin, lycopene	Dried stigmas are useful in bronchitis, anaemia, asthma, leucorrhoea, coughs, sexual debility, nephropathy and skin diseases
Eriodendron pentandra	Flowers rose or dark red with large flowers.	-	Menorrhagia, fever, urinary disorders, diarrhea, diseases of pitta, dysentery, gout, haemorrhage
Hibiscus mutabilis	Flowers white/pink.	Quercimeritrin, meatrin and cyanin	Respiratory disorders, Expectorant, Antidote to poisons and Anodyne. Recommended for persistent coughs, Menorrhagia
Jasminium sambac	Flowers white, solitary or in cymes, fragrant.	Triterpenes, sesquiterpenes, linallol, cis-caryophyllene, indole, cis-3-hexenyl benzoate and methyl anthranilate	Useful in foetid smell in ear and nose, eye diseases, vomiting in hypertension

or decoctions.

Use of Flowers for Therapeutic and Nutritional Purposes throughout History

The use of flowers in food and medicine dates back thousands of years. These usage were first documented in Mesopotamian and Egyptian cultures

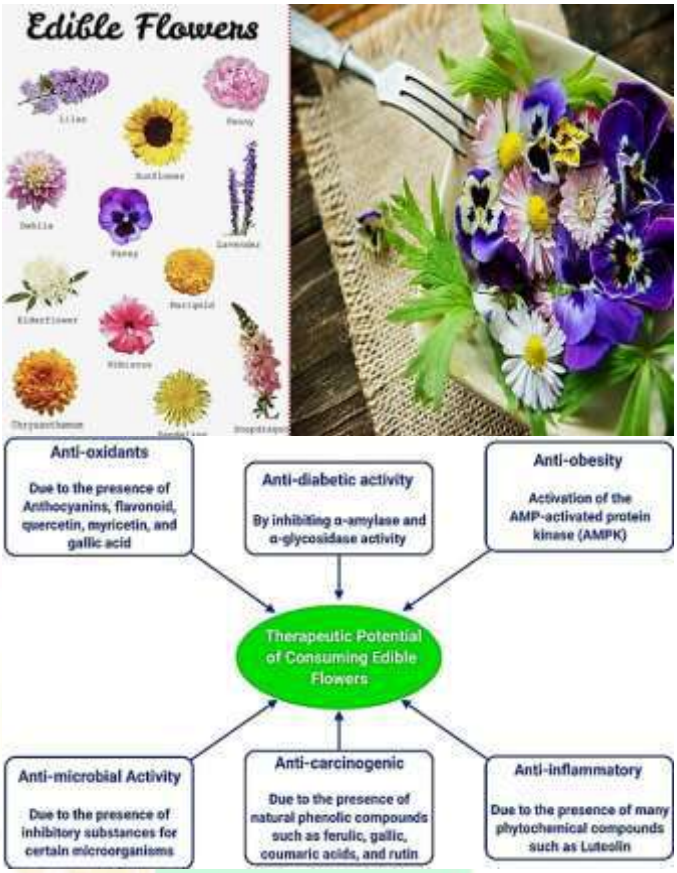
around 4000 BC. Chamomile (*Chamomilla recutita* L.), whose dried flowers have been used since ancient times to treat menstrual irregularities, sleeplessness, ulcers, hemorrhoids, and other diseases, is a prime example of the historic use of a flower for medicinal purposes (Srivastava *et al*., 2010). Similarly, cannabis (*Cannabis sativa* L.), known for its soothing and anticonvulsant properties, has been used therapeutically in many cultures. This plant was even included in the British and later American pharmacopoeia but was eliminated in the 20th century because of concerns about the risk of abuse and intoxication. The use of flowers in gastronomy is documented in various cultures, such as Roman, Greek, Chinese, Indian, and Central European, where they are used to enhance both the presentation and nutritional value of food. In ancient Rome, several roses were often used in omelettes and purées. In mediaeval France, marigolds were a common ingredient in salads. The stigmas of the saffron flower are one of the most commonly used colouring and flavouring agents in cooking. Similarly, violet petals were used to make sweets and colour sugar, while dandelion flowers were used in drinks and salads. Additionally, some of the vegetables that are frequently eaten in the Mediterranean diet are flowers, including cauliflower, broccoli, artichokes, and capers. Globally, countries like Brazil, the United States, France, Italy, Portugal, China, and Japan value and consume edible flowers like pansy, marigold, borage, nasturtium, mini rose, torenia, mini daisy, cosmos, clitoria, craving, begonia, sunflower, snapdragon and squash blossom.



Forms of Consumption: Edible flowers are manly used fresh as decoration or a garnish for some meals, such as salads or light curry, adding colour and fragrance. In addition, they are also used for other culinary purposes, such as ingredients in bread, pancakes, sauces, jellies, syrups, vinegar, honey, oils, soups, flower scented sugars, candied flowers, cheeses, ice-cream, juice and flavoured liqueurs. The flower are typically eaten whole, but these are some species of which only some parts are adequate for consumption. For example, some parts of flowers are too bitter, such as the white parts of the roses and the base of the chrysanthemum petals, or too rough, such as some parts of the blueweed (*Echium vulgare* L.). Other examples of flowers that are not eaten whole include tulips (*Tulipa* spp.) and chrysanthemums (*Chrysanthemum*) (only the petals are consumed), daisies (*Bellis perennis* L.) and garden nasturtium (*Tropaeolum majus* L.) (only the flower buds), and pumpkins (*Cucurbita* spp.) (only the tiny and undeveloped fruits with flowers) (Mlcek and Rop, 2011).

Flowers as Medicine Resource: Phytosterols (β-sitosterol), alkaloids, lignans, neolignanes, coumar-

ins and bisabolol oxides A and B are other phytochemicals distributed in edible flowers. However, these compounds are usually present in smaller concentrations. Among the beneficial actions attributed to various flowers are antioxidants, anti-inflammatory, anti-carcinogenic, anti-obesity, hepatoprotective, neuroprotective, gastro protective, anti-diarrheal, anti-infective, antitumor, antispasmodic, analgesic, and astringent, among others. However, studies have focused on the benefits these species can provide to the immune (31.5%), infectious (26.0%), and gastrointestinal (14.2%) systems. The flowers of begonias, roses, garden nasturtiums, daylily, calendula, Japanese rose, Daurian rose, daylily, and chrysanthemum might protect against oxidation, as there are studies indicating that they exhibit antioxidant capacity in vitro (Cai *et al*., 2005). According to certain research, several edible flowers may have anti-carcinogenic properties against malignancies of the liver, colon, brain, skin, bladder, prostate, or breast. Hibiscus, rose, chrysanthemum, tagetes, greater bougainvillea (*Bougainvillea glabra* Choisy), coral vine (*Antigonon leptopus* Hook. & Arn.), jasmine, honeysuckle rose, *Cassia fistula*, chives, calendula, and pomegranate are a few examples. Numerous flowers might have anti-inflammatory properties. Roselle, honeysuckle, daylily, wild chrysanthemum, and Hangzhou white chrysanthemum are a few examples. Flowers including waterlilies, rosellas, and magnolias have been shown to have anti-obesity properties. The research indicates that eating flowers can also have anti-diabetic, antibacterial, neuroprotective, and prevention of visceral damage, among other positive effects.



Conclusion

Flowers are a constant source of motivation and good vibes that also contribute to the enhancement of human well-being. Research has additionally demonstrated that owners may be a source of medicine discovery and development. Owers' phytochemical components have demonstrated their potent chemistry, aiding in the management of illnesses. Flowers have also demonstrated that they are more than just decorative items; they contain potions that may be used to heal major illnesses and chronic conditions. Additionally, flowers are a source of inspiration for future studies on flowers

flora and give their valuable presence to the food and nutrition, pharmaceutical, cosmetic, fragrance, spirituality, and decoration industries.

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Artificial Intelligence and IoT for Seed Quality Testing

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Introduction

The already overburdened farm sector was under immense strain from the constantly rising demand for food products due to population growth. The agriculture supply chain is frequently affected by climate change, and new technologies are required to guarantee increased crop yields. One important factor that guarantees high crop yields is the caliber of the seeds or seedlings. Since ancient civilizations, the need of high-quality seed has been recognized, with seed screening being used to increase crop quality and output (Medeiros, 2020). For agriculture and the growth of seedlings, seed quality is essential since it is directly linked to germination rate, plant performance, and tolerance to biotic and abiotic stresses, guaranteeing high output and greater revenues. Therefore, the seed industry constantly seeks ways to describe seed quality attributes accurately. These quality assurance programs in the seed industry employ various methods to verify seed quality parameters such as germination, viability, and vigor tests. Seed quality evaluation involves using reliable methods for continuously examining fresh and stored seeds for their physical and chemical properties, such as purity, germination, vigor, and freedom from debris, dead seeds, molds, pests, or any other signs of deterioration. The changes in the chemical composition and internal structural properties of seeds are typically connected with loss of viability, germination percentage, and vigor. However, conducting uninterrupted testing can be challenging, for example, when dealing with insects within the seeds without any external indications of infestation. Due to technological and time constraints, seed health, viability, damage, and vigor may be difficult to assess directly. The techniques applied for seed quality testing are usually impaired by time constraints, subjectivity issues, and the destructive nature (Elmasry *et al*., 2019). Time limits, subjectivity problems, and the destructive nature of the methods used for seed quality testing typically compromise their effectiveness. It takes a lot of effort and time to visually analyze each seed individually in a laboratory setting for traditional seed quality testing. An increase in inspection errors and inaccurate reporting results from employees' performance deteriorating over time and occasionally falling short of expectations. Recent advancements in Artificial Intelligence (AI) and the Internet of Things (IoT) have revolutionized the agricultural sector, offering innovative solutions for seed quality assessment. AI, particularly machine learning (ML) and deep learning (DL), enables the automated analysis of seed traits from digital images and sensor data, facilitating rapid and accurate classification, damage

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Table 1: Comparison of Traditional Vs. AI and IoT Based Seed Quality Testing

Method	Accuracy	Time Required	Cost	Automation
Manual Inspection	Moderate	High	Low	No
Germination Tests	High	High	Medium	No
AI-Based Image Processing	Very high	Low	High	Yes
IoT-Enabled Monitoring	High	Real-time	Medium	Yes

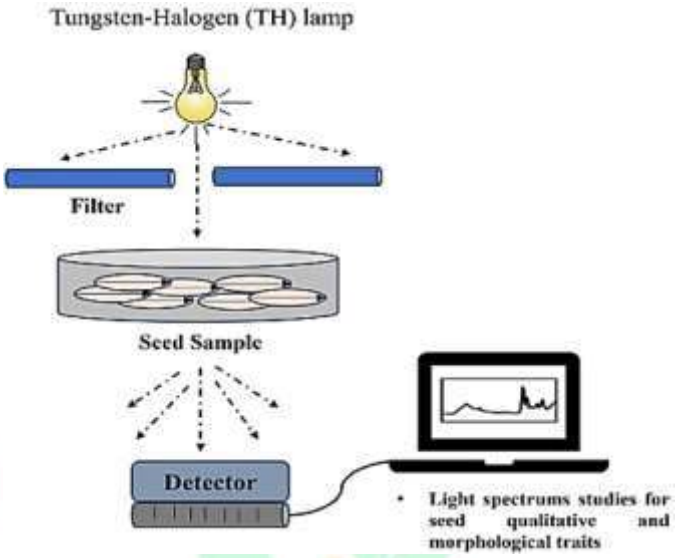
detection, and viability prediction.

Internet of Things (IoT) in Seed Monitoring and Quality Control

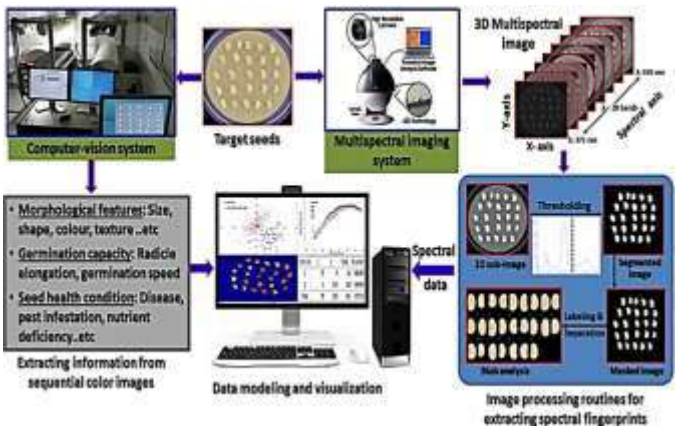
The Internet of Things (IoT) has emerged as a transformative technology in agriculture, offering real-time monitoring and data collection capabilities essential for maintaining seed quality. By integrating IoT devices with advanced analytics, farmers and agronomists can ensure optimal conditions for seed storage, germination and growth.

Environmental Monitoring: IoT sensors are deployed to continuously monitor environmental parameters critical to seed quality, such as temperature, humidity and soil moisture. Maintaining these parameters within optimal ranges is vital for seed preservation and successful germination. For instance, Ather *et al*. (2024) developed an Arduino-based IoT framework that monitors air and soil moisture, enhancing sunflower seed yield by ensuring ideal growing conditions.

Automated Sorting Systems: When combined with artificial intelligence (AI) models, Internet of Things (IoT)-enabled devices make it easier to automate the sorting and grading of seeds. These systems classify seeds according to predetermined quality parameters by using sensors and image technology to evaluate seed characteristics including size, shape, and color in real-time. In addition to increasing productivity, this automation lowers human error in the evaluation of seed quality.



Data Analytics and Cloud Computing: IoT devices generate vast amounts of data that, when analyzed through cloud-based platforms, provide actionable insights for improving seed quality and storage practices. Real-time data analytics enable the detection of environmental fluctuations that may adversely affect seed viability, allowing for prompt corrective actions. Moreover, historical data analysis aids in optimizing storage conditions and predicting germination success rates.



Identification and Selection of High-Quality Seeds Using Artificial Intelligence

Agriculture is always evolving, and technology is increasing sustainability and productivity. The application of artificial intelligence (AI) to identify and choose premium seeds is among the most significant advancements. By 2050, there will be 9.8 billion people on the planet, requiring 14,886 million tons of world cereal equivalent (CE) food. Improving seed quality is essential to increasing crop yields and ensuring sustainable farming practices. AI-assisted seed identification could revolutionize agriculture by increasing crop productivity and resilience.

Image Recognition and Computer Vision for Seed Quality: Analyzing the physical characteristics of seeds using computer vision and image recognition technologies is one of the most direct applications of AI in seed identification. Specific physical characteristics, such as consistency in size, shape, color, and surface roughness, are often exhibited by high-quality seeds. These characteristics have a direct bearing on the seed's capacity to sprout and develop in a certain setting. AI-powered image recognition allows seeds to be scanned and examined at the microscopically level. This makes it possible to detect minute details that are invisible to the naked eye, like hidden cracks or surface flaws. AI may be able to provide real-time information on the health and viability of seeds by analyzing these characteristics, which would make it easier to distinguish between high- and low-quality seeds with surprisingly high accuracy (Jiang, 2024).

Predictive Analytics for Germination Success: In addition to visual traits, AI can forecast how well a seed will function based on historical data, including soil conditions, weather patterns, and prior crop performance. Predictive analytics, powered by machine learning algorithms, may give useful insights about which seeds are likely to provide the greatest outcomes in various conditions. AI-driven predictive models can evaluate massive quantities of data to create very accurate forecasts about the probability of seed germination and subsequent crop performance (Javaid *et al*., 2023). AI can examine genetic data to identify seeds that are not only physically healthy but also genetically inclined to excellent performance. By merging genetic information with environmental data, AI systems may give more thorough seed selection techniques. For example, AI may discover seeds with certain gene combinations that produce maximum performance in a given soil type, climate, or under specialized farming techniques such as organic or hydroponic systems.

Automated Seed Sorting Systems: Seed sorting is a labor-intensive process that could be automated with AI-driven robotic devices and real-time data (Kaushik *et al*., 2024). Robots powered by AI are able to quickly and accurately sort vast amounts of seeds based on a variety of characteristics, including size, shape, and color. To guarantee that only the best seeds are chosen for sowing, these robots may be built to reject seeds that don't meet the required

standards. Automated sorting systems have the potential to significantly reduce human error, resulting in a more consistent and precise seed selection process.

Detection of Infections and Diseases: In the food industry, microbial deterioration and insect invasion provide serious obstacles that call for accurate identification and preventative measures. In addition to being vulnerable to insect and pest infestations, seeds undergo a variety of biological and physico-chemical changes during storage, which can result in significant losses in terms of both quantity and quality. The presence of dockage, a high percentage of broken seeds, and high moisture levels all contribute to the favorable conditions for these infections. These losses can be lessened or even prevented by putting in place suitable storage procedures and keeping a close eye out for any indications of infection before further development.

Conclusion

In agricultural and food research, artificial intelligence is a cutting-edge technology that is being used more and more for noninvasive, noncontact evaluation of the thermal characteristics of various foods. This method links intrinsic quality features to thermal measurements. The surface temperature of the objects under analysis largely determines the radiation they produce. As a result, increasing the target products' temperature causes more radiation to be released. The monitoring of seeds and the assessment of their quality have been done using thermal imaging. Advancements in detector design, hardware modifications, and enhanced capabilities of digitized image-processing algorithms are expected to drive the tech nology toward more practical applications, particularly in high-through-put settings within the seed industry where traditional methods are not viable.

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Transforming Animal Science through Artificial Intelligence (AI)

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Introduction

In this modern era of the industrial revolution 4.0, almost all activities of human life cannot be separated from the use of information technology (IT) as an enabler for other activities and services. IT is no longer just a tool and is now a required component that must be owned. Its advancement, which significantly facilitates human life activities, has resulted in a high reliance on the existence of information technology (Rahmatullah *et al*., 2022). In addition, since technology plays a much more significant role in the digital era than it did in previous generations, today's generation is technologically literate. The rise in literacy, combined with recent technological advancements, has resulted in expanding technology in education. These are the generations entering the classroom today, ranging from millennials to Gen-Z, and they all share distinct characteristics that define their age. These generations expect to be actively engaged in their learning and do not perform well as passive learners. As a result, technology must be embraced in today's education, and teachers must incorporate technology into their students' learning (Hashim, 2018). Rapid advances in big data and artificial intelligence technologies have profoundly impacted all aspects of human society, including the economy, politics, science, and education. Artificial intelligence (AI), a machine-based technique with algorithmic power for making predictions, diagnoses, recommendations, and decisions, has gained prominence in the educational community in recent years due to its potential to support learning in various contexts. With diverse applications such as intelligent tutors for content delivery, feedback provision, and progress supervision, the field of AI in education has demonstrated technological advances, theoretical innovations, and successful pedagogical impact. Up until 2010, cultivators required to monitor their fields and spot flaws using the Global Positioning System (GPS), satellite maps, ground-based sensing platforms and local sensing tools like data recorders. Digital agriculture (DA) and smart farming techniques moved toward digitalization with the advent of Unmanned Aerial Vehicles (UAV), low-powered long-range wireless sensors, Internet of Things (IoT) devices, and robotics (Basso and Antle, 2020). They contributed to the economic development and sustainability of food production. Indian farmers are predominantly small holder farmers (SHFs), and there are more than 40 critical farming activities that need attention and decision support to ensure good yields and returns on investment. New and emerging technologies such as the internet of things (IoT), drones, mobility, cloud computing, big data, remote sensing, artificial intelligence (AI),

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machine learning (ML), image analytics and processing, block chain, and agribots are poised to transform traditional agriculture into data-driven precision farming to generate sustainable profits (FICCI, 2022). Digital technologies can create promising business opportunities in agriculture and at this juncture, farmer has to be made a partner in the emerging business space from the start. It will not be an easy task given socio-political-economic conditions prevailing in the country.

Aims of artificial intelligence (AI)

Enhanced Efficiency and Automation: AI is designed to automate repetitive and mundane tasks, freeing up human resources to focus on more complex and creative endeavors. This leads to increased efficiency and productivity in various industries and domains.

Data Analysis and Decision-Making: AI can process and analyze vast amounts of data quickly and accurately, providing valuable insights and supporting data-driven decision making. This helps businesses and organizations make informed choices to improve processes, strategies, and outcomes.

Prediction and Forecasting: AI can predict future outcomes and trends based on historical data and patterns. This predictive capability helps in planning and strategizing for the future, whether in financial markets, weather forecasting, or customer behavior.

Personalization and Tailored Experiences: AI enables personalized experiences by understanding and adapting to individual preferences and behaviors. This applies to various aspects, such as personalized recommendations in e-commerce, content customization, and adaptive learning.

Problem-Solving and Optimization: AI can solve complex problems and optimize processes by evaluating numerous variables and finding the most efficient solutions. This is particularly useful in areas like logistics, resource allocation, and manufacturing.

Natural Language Understanding and Communication: AI, especially Natural Language Processing (NLP), allows machines to comprehend, process, and generate human language. This facilitates effective communication, chatbots, language translation, and more.

Enhanced Safety and Security: AI contributes to safety by monitoring and predicting potential risks in various domains, including cybersecurity, public safety, and autonomous vehicles.

Creative and Artistic Expression: AI can generate creative content, such as music, art, and writing, showcasing the potential for collaboration between human creativity and machine intelligence.

AI in Livestock Management

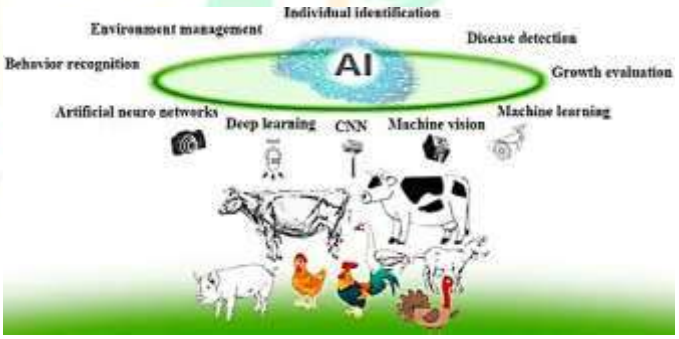
Accurate prediction of animal weight, which is crucial for improving the efficiency and sustainability of livestock management practices, often involve labor-intensive procedures and lack instant and non-invasive solutions. The application of AI in livestock management eliminates the need for physical contact, improves animal welfare and also mitigates potential risks. For instance, machine learning algorithms have been employed to forecast

livestock supply and outputs, automatically classify cow behavior, and predict livestock weight. In the area of genomics, machine learning models have been utilized to identify cattle breeds using SNP panels, showcasing its potential for advancing livestock genetics. Overall, the studies highlight the power of AI in optimizing farming processes, reducing costs, and improving sustainability in livestock production.

Fig. 1: Applications of AI in Livestock

Genetics and AI: Through the application of machine learning models, scientists can analyze extensive datasets to forecast genetic traits, enhance breeding programs, and boost disease resistance. These studies span a range of applications-from predicting genomic traits in livestock like cattle and chickens to pinpointing crucial genes within animal models highlighting AI's vital role in accelerating research progress and improving accuracy in livestock management. Machine learning supports the discovery of intricate patterns and associations within genetic data, making it a critical tool for enhancing breeding program efficiency and promoting progress in animal biotechnology. The integration of AI in genetic research not only drives productivity but also supports sustainable agriculture and the preservation of important genetic resources in animal populations.

Embryo Transfer and AI: Embryo transfers are prone to errors, inconsistent manual grading of bovine embryos, and embryologist unavailability, particularly in the cattle business where visual assessment and selection of embryos are done by embryologists. The incorpo-ration of machine learning into one important development in animal biotechnology is the use of embryo transfer methods. When paired with machine learning algorithms, spectroscopy and video microscopy in bovine reproduction are improving pregnancy success rates by allowing for more accurate forecasts of embryo viability and transferability (Shivani and Madan, 2024). These AI-powered devices are being used for more specialized purposes, like checking for toxicity to embryo-fetal development, on species other than cattle, like Iberian ribbed newts (Saiki *et al*., 2024).



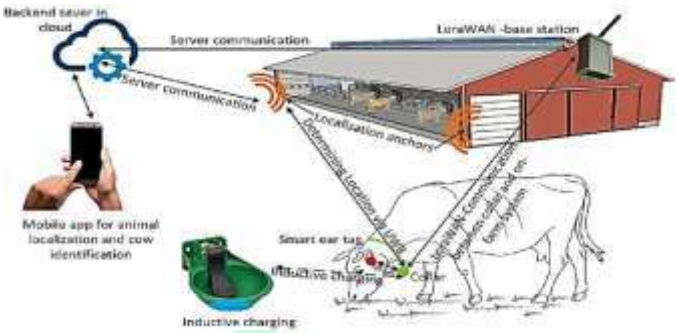
Selective Breeding and AI: Despite the fact that genomic selection in animal breeding has been revolutionized by modern genotyping methods, the vast marker datasets have many limitations with regard to computational capacity, accuracy, and flexibility. Because machine learning algorithms are so flexible and can identify trends in big, noisy datasets, they present interesting solutions for animal breeding applications. Animal breeding is undergoing a revolution thanks to the use of machine learning into genomic research and selective breed-

ing. Additionally, the use of AI and machine learning in bioinformatics simplifies the processing of genomic data, increasing the efficacy of selective breeding for a range of animal species. These developments are especially important for promoting sustainable farming methods and maximizing animal output and health.

Widely Used Automation in the Dairy Sector

Automation has assisted dairy farm owners in overcoming the challenges of locating workers willing to perform manual labor at dairy farms with the aid of lasers, sensors, and data collection. One benefit of automation is that animals appear to have adapted to this new technological trend and prefer robots.

Drones: Drones are quickly becoming an important tool in the dairy sector. While farmers are familiar with traditional technologies, they are increasingly calling for the use of drones to take on more complex tasks. For example, drones can be used to check fences and the herd in general, as well as to help herd cows from fields to barns. Furthermore, drones are being used by modern dairy farms to map, examine, and photograph pastures in order to monitor growth. The sophisticated algorithms powering the drones are even capable of recognizing cows specifically and distinguishing them from deer or other similar animals. This has been a great asset to the dairy industry, as it can help farmers save time and money by automating the process of herding cows. In addition, drones can be used to monitor animal health, identify and track diseases, and provide early warnings of potential issues. The data collected by drones can then be analyzed to improve herd management strategies. Taken together, the use of drones in the dairy sector has been a major boon for farmers, offering a host of benefits that would not be possible with traditional technologies.



Robots: Robots are becoming increasingly popular in the dairy sector, thanks to their ability to increase productivity, reduce labor costs, and improve biosecurity measures. The most common use of robots in the dairy sector is robotic milking machines or milk bots. These machines are designed to automatically identify the teats and milk of the cows, while also cleaning the udders. Milk bots have been found to be both efficient and time-saving, with some studies suggesting that they can reduce the time spent on milking by as much as 30%. Furthermore, they can also reduce labor costs, as they do not require human labor to operate. Robots can also be used to clean and sanitize the barn, improving biosecurity measures and creating a healthier environment for the cows.

Augmented Reality: Augmented reality (AR) is an innovative technology that enables the real-time blending of digital data with the environment experienced by the user. It has been found to be

highly beneficial in many different applications, such as increasing the visual appeal of food and accurately determining the right serving sizes. Furthermore, AR can also be used to monitor and assess cows for producers. For example, AR can provide farmers with real-time data on the health and well-being of their animals, allowing for more efficient and effective management of their livestock. Additionally, AR can be used to improve the accuracy of milk yield estimation and to better identify potential health issues. The use of AR in the agriculture industry has a number of potential benefits. For instance, it can help to reduce the labor costs associated with traditional methods of animal monitoring and assessment, while also providing more accurate data. Additionally, it can help to reduce the risk of human error when recording and analyzing data, thus improving the accuracy of results. Furthermore, AR can also be used to provide farmers with helpful information about their animals such as body temperature, body composition, and nutrition levels.

Challenges in the Use of AI in Animal Production Sciences

The application of artificial intelligence (AI) to the sciences of animal production is rife with difficulties, despite its enormous potential. The broad use and effectiveness of AI systems are constrained by several problems, which have technical, infrastructure, socioeconomic, and ethical components.

Data-Related Challenges: Effective AI models require large volumes of high-quality, labeled data for training. However, in animal production systems, data is often fragmented, inconsistent, or unstructured. For example, reliable datasets on animal behavior, health events, or environmental conditions are either unavailable or vary widely across regions. Wearable or embedded sensors used for collecting data on livestock health, behavior, and productivity may suffer from calibration issues, battery failures, or data loss, affecting the performance of AI algorithms (Rutten *et al*., 2013).

Technical and Integration Barriers: Animal physiology and behavior are influenced by multi-factorial interactions involving genetics, nutrition, environment, and management. Capturing this complexity accurately through AI remains a technical challenge (Neethirajan, 2020). There is no universally accepted protocol for data collection, model training, or AI tool validation in animal sciences. This lack of standardization hinders interoperability and benchmarking (Gonzalez-Recio and Alenda, 2020). In rural or resource-poor settings, poor internet connectivity, lack of digital infrastructure, and unreliable power supply impede real-time AI applications.

Cost and Economic Viability: The implementation of AI technologies-such as smart sensors, data processing infrastructure, and software licenses requires significant capital, which is often unaffordable for smallholder farmers and developing countries. While AI promises long-term savings and productivity gains, many farmers are hesitant to

adopt it due to uncertainty about the return on investment, especially in variable market conditions.

Human and Knowledge Barriers: Farmers and animal science professionals often lack the necessary technical skills to operate AI systems, interpret outputs, or troubleshoot hardware/software issues (Aung *et al*., 2020). Traditional mindsets and reluctance to adopt new technologies persist in many farming communities, especially where AI is perceived as complex or threatening to jobs.

Ethical and Regulatory Concerns: While AI can promote animal welfare through better monitoring, excessive surveillance may raise ethical questions about autonomy and natural behavior (Cang *et al*., 2020). Issues of data ownership, privacy, and misuse are emerging concerns, particularly when data is collected by third-party commercial platforms without transparent agreements.

Conclusion

The rapid evolution of machine learning and artificial intelligence in animal biotechnology marks a significant shift toward more efficient, data-driven approaches to managing livestock and improving agricultural productivity. Traditional methods employed in various domains of Animal Biotechnology, often involve procedures which are time-consuming, expensive, labor-intensive, stressful, inconsistent, lack instant and non-invasive solutions. The application of AI and ML in Animal Biotechnology not only enhance traditional methods but also provide novel solutions for challenges such as disease detection, breeding optimization, environmental sustainability, reducing failures and costs as well as improving efficiency.

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Application of Nano Fertilizer in Agriculture

Narayan Dattatraya Totewad

Introduction

To address the significant concerns of sustainable food production and development, several great technological advances have occurred in recent years in the field of farming. Innovation in agriculture is important to meet global food demand because of rising natural and synthetic resources. Nanotechnology may be used to solve a variety of agribusiness-related problems (Shang *et al*., 2019). There is a great scientific interest in bridging the gap between bulk materials and atomic or molecular structures, which can be accomplished with the aid of nanoparticles. In the last two decades, a lot of research on nanotechnology has been performed in agriculture sectors. Although fertilizer application is essential for raising agricultural output, over fertilization reduces the amount of land that may be used for crop production. Agrochemical use must be kept to a minimum in sustainable agriculture in order to preserve biodiversity and the ecosystem. Nano-materials can help increase the quality of agri-inputs to increase crop productivity. Crop yields have increased as herbicides using nanotechnology have grown in sophistication. As research is done to adapt plants to changing temperatures without damaging current ecosystems, food sustainability is the primary concern in agricultural production.

Controlling soil and plant quality and health are a plus for sustainable agriculture and conservation of climate (Chen *et al*., 2016). Another cutting-edge technique in agriculture that may make it possible to produce agricultural fields more effectively is nanotechnology. Nanotechnology could potentially reduce waste and human capital. Short-term fixes for the challenges of contemporary industrial agriculture are offered by agro-nano-technologies. Since fertilizer management and the connections between soil, plants, and water have a significant impact on crop production systems, nutrient efficiency is one of the most pertinent concepts for evaluating them. Enhancing research on nutrient use efficiency is difficult and highly relevant nowadays. To guarantee maximum yield and support soil and crop health, nutrients are added to crops and cropping systems. Nano-fertilizers are nutrient carriers of nano-dimensions ranging from 30 to 40 nm (10^{-9} m or one-billionth of a meter) and capable of holding bountiful of nutrient ions due to their high surface area and release it slowly and steadily that commensurate with crop demand. Nano-fertilizers have high use efficiency and can be delivered in a timely manner to a rhizospheric target. There are slow-release and super sorbent nitrogenous and phosphatic fertilizers.

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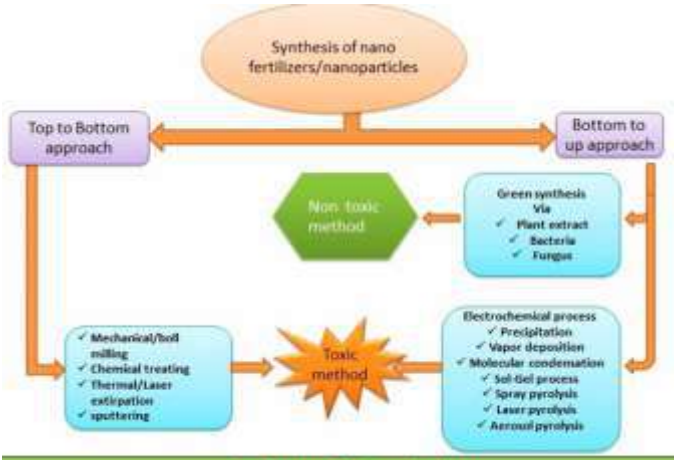
Synthesis of Nanofertilizer: Nanoparticles can be synthesized by three processes, i.e., by physical, chemical, or biological route. Chemical route employs toxic chemicals and is energy intensive, thereby precluding biomedical applications. In physical method, narrow size dis tribution of the particles or monodispersity is often difficult to attain, whereas biological method (intracellular and extracellular) is more cost-effective and green method. For the application point of view, there is a need to develop green synthesis procedure for synthesis of metal nanoparticles. Nanomaterials for nanofertilizers can be synthesized by different approaches like topdown and bottom-up, under which different physical, chemical and biological methods are used. The top-down approach is based on the reduction of size to nanoscale well-organized assemblies from the bulk materials. The limitation of this approach is the low control of the size of nanoparticles and a greater quantity of impurities. The bottom-up approach initiates at a very basic level, using atomic or molecularlevel chemical reactions to build up nanoparticles. Being a chemically controlled process, this approach has the benefit of controlling the particle size and reducing the impurities in a better way.



Synthesis of Nano-fertilizer

Nanocomposites

In order to provide a variety of nutrients with desired qualities, nanocomposites have been developed. These substances have the ability to control inputs based on crop requirements or soil conditions. The controlled release of nutrients that influence plant growth has been achieved through the use of zinc–aluminum layered double-hydroxide nano-composites. Because they are wet and porous, nanomaterials in soil niches regulate permeability, moisture retention, solute transport, and plant nutrient availability. Additionally, these nano-particles regulate the exchange processes of dissolved organic and inorganic species between colloidal surfaces and soil solution. A large amount of reactivity to soil biological and abiotic processes is provided by the physicochemical characteristics of nanocomposites' surfaces. In accordance with the rule of nutrients demanded by wheat, Zhang *et al*.

Table 1: The difference between conventional fertilizers and Nanofertilizers

Properties	Nanofertilizer	Conventional fertilizer
Solubility	High	High
Bioavailability	Low	Low
Rate of nutrient loss	Low loss of fertilizer nutrients	High loss of fertilizer nutrients
Dispersion of mineral	Improved dispersion of insoluble	Lower solubility due to large size particle
The efficiency of nutrients uptake	Enhanced uptake ratio and saves fertilizer resource	It is not available to roots and the efficiency of nutrients uptake is low
Soil adsorption and fixation	Reduced	High

(2006) reported that measurements of the nutrients of wheat plants revealed that the contents of NPK absorbed by wheat during the shooting period were higher in treatments with the five types of bulk-blended SRFs than in chemical fertilizer of equal amount of NPK. Liu *et al*. (2006) investigated the superabsorbent nitrogen fertilizers (SSNF) slow-release nitrogen behavior in water as well as the soils' ability to retain water. They found that the surface cross-linked product exhibited outstanding soil moisture preservation capabilities in addition to good slow-release properties, which could significantly enhance the simultaneous use of water and fertilizer resources. Additionally, they discovered that SSNF might be used in horticulture and agriculture, particularly in regions that are prone to drought and have limited water supplies. According to Liu and Zhang (2005), the soil's structure and penetrability were greatly impacted or controlled by the nano-subnanocomposites, which also increased the soil's organic mineral granules, improved the soil's capacity to store fertilizer and hold water, encouraged microbial activity, controlled the C/N ratio, improved the soil's fertility, and more. Fertilizers incorporated with cochleate nanotubes (rolled-up lipid bilayer sheets) have been shown to produce higher yields.

Mode of application of Nanofertilizers

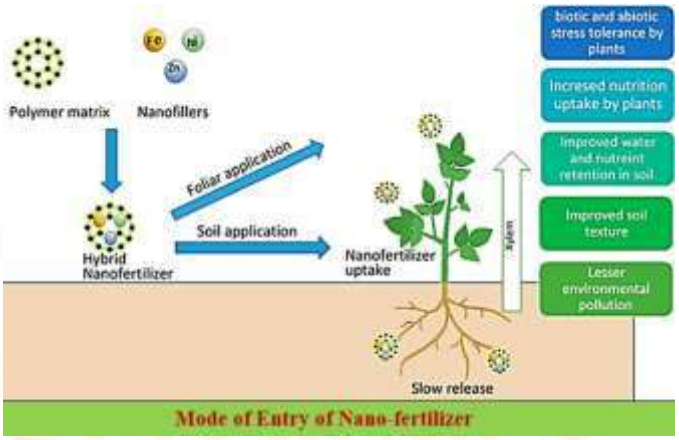
Foliar: The physiology of the plants determines how well the nanoparticles are absorbed. Nanoparticles (NPs) are typically carried throughout the plant by the phloem and xylem after being absorbed by the trichomes, stomata, stigma, and hydathodes. There are two mechanisms for NPs to translocate: apoplastic and symplastic pathways. The apoplast, or cell wall and other intercellular spaces, is where macromolecules (such as NPs, water, etc.) travel in the apoplastic route. However, the size exclusion limits (SELs) of cell walls (5-20 nm) restrict the movement of such macromolecules in this transport. However, in the case of the symplastic pathway, the movement of macromolecules (NPs) from one cell to another cell occurs by plasmodesmata which is an inner side of the plasma membrane. The NPs can enter the cells from the cell wall by endocytosis. The entry of the nanoparticles through the plant cell wall is determined by the diameter of the stomata, which varies from 5 to 20nm, or by the base of the trichrome, and then they are transferred to the tissues (Samaj *et al*., 2004).

Roots: NPs penetrate through epidermis of the root crosses endodermis reaches the xylem, where they are transported to the aerial part of the plant. NPs enter the cell wall through pores, when they are

between 3 and 8 nm (Rajput *et al*., 2020). Because the Casparian strip has wounds, NPs can also enter at the root tip meristem or at the locations of lateral root development. NPs need to pass through plasma membranes and cell walls in order to reach the roots' epidermal layers. They then go into the vascular tissues, or xylem. Cell walls have pores that are between 3 and 8 nm in size, which is extremely small for NPs to enter. Nevertheless, it has been demonstrated that NPs cause the formation of huge pores in cell walls where they can be internalized. The microelements enter the plant through the hairs of the feeder roots. Thus, Ca, Mg, Fe, S or Zn encapsulated microspheres, are dissolved by the organic acids or phenols of the root exudates. After the application of fertilizers in soil, much of the nutrients are lost due to leaching as a consequence of which soil and water are polluted. Not only this, certain agro chemicals are responsible for greenhouse gases and climate change.

Mode of Entry

Plant cell wall acts as a barrier for easy entry of any external agents including nanoparticles into the plant cells. The sieving properties are determined by pore diameter of cell wall ranging from 5 to 20 nm. Hence, only nanoparticles with diameter less than the pore diameter of the cell wall could easily pass through and reach the plasma membrane. There is also a chance for enlarge ment of pores or induction of new cell wall pores upon interaction with engineered nanoparticles which in turn enhance nanoparticle uptake. Further internalization occurs during endocytosis with the help of a cavity-like structure that forms around the nanoparticles by plasma membrane. They may also cross the membrane using embedded transport carrier proteins or through ion channels. In the cytoplasm, the nanoparticles are applied on leaf surfaces; they enter through the stomatal openings or through the base of the trichomes and then translocated to various tissues.



Achievements of Nanofertilizers: Several research studies have shown that the application of Nano-fertilizers lead to improving crop yield. This is primarily because of enhanced photosynthesis from increased growth of plant parts and enhanced metabolism, leading to higher accumulation and translocation of photosynthesis. Foliar application of nanofertilizer greatly improved yield of crops. The availability of nutrients can be enhanced by nano-fertilizers. By speeding up the chemical reaction or synthesis process in plant cells, this helps to raise quality metrics like the amount of protein, oil, and sugar in plants. The amount of total carbohydrates, starch, indole-3-acetic acid, chlorophyll, and protein in crops rose when zinc and iron were nano-formul-

ated.

Conclusion

From the standpoint of sustainable agriculture, nanotechnology holds promise for creating novel fertilizers like Nanofertilizer, which would boost global food production and feed the world's growing population. Because of their vast surface areas and slow, constant nitrogen release, NFs have the potential to be used into smart crop production systems within the framework of sustainable agriculture. They are ideal for usage in contemporary agriculture because of these encouraging qualities. Utilizing NFs can boost agricultural output and resilience to both biotic and abiotic stressors. As a result, it is impossible to overlook the application of NFs in the agricultural industry. Through the intelligent administration of active chemicals, NFs may help reduce fertilizer usage, boost nutrient absorption and NUE values, and reduce fertilizer losses due to volatilization, leaching, runoff, and energy consumption during production.

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Advanced Extraction and Profiling Technologies for Phytomolecules

Pooja Chak, Deepti Chaudhary and Ajay Baldaniya

Introduction

The current global food system is not legitimate and it gets affected with its stability due to resilience in climate and ecosystem. A large portion of the world's population is found to be suffering from malnutrition which includes undernourishment, overweight and micronutrient deficiencies due to unhealthy diets (Springmann *et al*., 2018). Nutrient deficiency is the red flagged concern in various developing countries, which leads to serious health ailments. As humans are reported to have various malnutrition problems during their growth, those problems can be resolved by regular intake of essential nutrients, vitamins and minerals from plant sources (Mushtaq *et al*., 2021). Global fruit and vegetable production has expanded thanks to sustainable agriculture and advancements in agricultural technology. Plant-based diets are reportedly lowering the death rate and other infectious illness rates. There are several types of plant-based diets, including lacto-ovo-vegetarian, vegan, flexitarian, and semi-vegetarian diets. Plant production via intensive cultivation and obtaining them for ingestion opens the door for people to regularly consume the appropriate amount of nutrients.

Phytochemicals and phytonutrients have been essential for ages in preserving homeostasis worldwide. By emphasizing their therapeutic, nutraceutical, and food fortification benefits, these naturally occurring chemicals are extracted using a variety of extraction techniques. Many life-saving medications have been developed as a result of the identification and extraction of bioactive chemicals from medicinal plants. A few of instances of how traditional botanical knowledge has influenced medication discovery are aspirin, which is derived from the salicin present in Salix species, and artemisinin, which is isolated from Artemisia annua. Nature continues to provide an unmatched source of innovative treatments, even in the face of tremendous advancements in synthetic drug research. Antibiotic resistance, the rise in infectious pathogens, and the frequency of chronic illnesses have made it necessary to keep looking into traditional medicine for alternate forms of treatment. Furthermore, because of their price and accessibility, traditional herbal remedies continue to be the main or supplemental type of healthcare in many impoverished nations. These factors highlight the relevance of plant-derived compounds in modern pharmaceutical

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research, underscoring the need for scientific validation and integration of traditional medicine into contemporary healthcare frameworks (Lewis, 2017).

Advanced Extraction Technologies

Integrating bioactive compounds from plant materials is critical in exploring their medicinal properties. Over time, traditional extraction methods, such as maceration and decoction, have been supplemented by more sophisticated, high-efficiency techniques that yield higher purity and better preservation of bioactive components. Among these, solvent extraction and supercritical fluid extraction are two advanced methodologies that have garnered significant attention for their ability to extract compounds efficiently and selectively. Solvent extraction remains one of the most widely used techniques for isolating phytochemicals. It involves using solvents like ethanol, methanol, acetone, or hexane, which dissolve the plant material's bioactive compounds. The solvent is then evaporated, leaving behind the extracted compounds. While solvent extraction is highly effective for extracting a wide range of compounds, it does come with certain limitations, such as solvent toxicity and the risk of thermal degradation of heat-sensitive compounds. Additionally, residual solvents can sometimes remain in the extracts, requiring careful purification (Altemimi *et al*., 2017).

Supercritical Fluid Extraction (SFE): Supercritical fluid extraction is a cutting-edge method for isolating bioactive chemicals selectively that uses fluids above their critical temperature and pressure. Because of its non-toxicity, mild critical characteristics (31.1 °C and 73.8 pressure), and environmental compatibility, carbon dioxide (CO_2) is the most commonly utilized supercritical fluid. By combining a liquid-like solvating capacity with gas-like diffusivity, CO_2 facilitates effective penetration into plant matrices and improves target molecule recovery without resulting in heat deterioration. The process starts with the introduction of pressurized CO_2 after plant material has been loaded into an extraction chamber. Supercritical fluid extraction offers multiple advantages, including solvent-free extracts, minimal downstream processing, precise selectivity and effective preservation of heat-sensitive compounds. Furthermore, the recyclable nature of CO_2 contributes to the environmental sustainability of this technique.

Subcritical Water Extraction (SWE): Subcritical Water Extraction (SWE) is an eco-friendly extraction method that utilizes water at temperatures between 100 and 374° C under sufficient pressure to maintain its liquid state. Under these subcritical conditions, the dielectric constant of water decreases significantly, enhancing its solvating power for moderately polar and polar bioactive compounds. This alteration in the physicochemical properties of water allows for the efficient extraction of thermolabile and polar phytochemicals, which are essential for Pesticide formulations.

Microwave-Assisted Extraction (MAE): Microwave-assisted extraction is an advanced technique

that employs microwave energy to heat solvents in direct contact with plant matrices, facilitating the efficient recovery of bioactive compounds. The underlying mechanism is based on dipole rotation and ionic conduction, in which microwave radiation induces rapid molecular movement. This results in effective cell wall disruption and accelerated mass transfer of the target molecules into the solvent phase (Khot *et al*., 2020).

Ultrasound-Assisted Extraction (UAE): A cutting-edge method called ultrasound-assisted extraction uses high-frequency sound waves (20-100 kHz) to improve the extraction of bioactive chemicals from plant materials. The basic process relies on acoustic cavitation, where localized high pressures and temperatures are produced by the quick creation and collapse of microbubbles. Plant cell walls are broken down by this mechanical process, which greatly increases solvent penetration and speeds up mass transfer.

Enzyme-Assisted Extraction (EAE): It is a biotechnological technique that releases intracellular bioactive chemicals from plant matrices by using particular enzymes that break down cell walls, such as cellulases, hemicellulases, and pectinases. The idea behind EAE is the targeted hydrolysis of complex polysaccharides in the cell wall, which improves the desired phytochemicals' bioavail-ability, extraction effectiveness, and specificity all of which are essential for the development of biopesticides. Pre-treating finely ground plant material with a specific enzyme concentration under regulated pH, temperature, and time conditions is part of the process. Since enzymatic action compromises the integrity of the cell wall, active secondary metabolites can be recovered mildly without undergoing chemical degradation.

Modern analytical techniques: The creation of biopesticides has been transformed by contemporary analytical methods like HPLC, MS, and Metabolomic Profiling, which make it possible to precisely characterize and quantify phytochemicals chemically. These techniques are essential for locating and maximizing the bioactive substances in plant extracts. When it comes to separating intricate plant mixtures, identifying particular chemicals of interest, and accurately and sensitively measuring them, HPLC is essential. This ability guarantees the uniform formulation and efficacy of biopesticide products by enabling researchers to pinpoint the precise bioactive chemicals causing insecticidal activity. By looking at the entire range of plant metabolites, including primary and secondary metabolites, metabolic profiling expands on this approach.

Challenges in Isolation and Purification of Phytomolecules

It is still difficult to separate and purify bioactive chemicals from plant materials, even with major advancements in extraction and analytical procedures. The complexity of plant matrices, which are made up of a vast variety of chemical compounds, is one of the main obstacles. Because they are frequently found in low concentrations with

other, less desirable compounds, their intricacy can make choosing desired chemicals challenging. It may also be difficult to extract and purify the bioactive chemicals due to their variable polarity, solubility, and stability. The presence of interfering substances such as pigments, carbohydrates, lipids, and proteins in plant extracts can also hinder the isolation process. These compounds may co-elute with the target bioactive molecules, reducing the purity of the isolated compound. To address this, additional purification steps, such as fractional crystallization, liquid-liquid partitioning, or solid-phase extraction, are often required to remove these contaminants. Another challenge is sensitive compounds' thermal and oxidative degradation during extraction and purification. Many bioactive compounds, especially those with antioxidant or anti-inflammatory properties, are prone to degradation under prolonged heat, light, or oxygen exposure. As a result, careful control of extraction conditions, such as temperature, time, and solvent choice, is crucial to preserving the integrity of these compounds.

Conclusion

Research on new phytochemicals in traditional medicine has shown a great deal of promise for improving the creation of new drugs. Researchers have discovered a wide range of plant-derived molecules that can help with a number of medical issues through the isolation of bioactive compounds and pharmacological profiling. Phyto-chemicals provide an extensive and untapped resource for drug development, ranging from antibacterial agents to anti-cancer and neuro-protective molecules. The efficiency and purity of chemical separation have been greatly increased by developments in isolation techniques, such as solvent extraction, supercritical fluid extraction, and other chromatographic procedures, which have allowed for a better comprehension of the compounds' potential for therapeutic use. Advanced extraction techniques provide significant improvements in the recovery, stability and preservation of bioactive compounds by utilizing controlled physical para-meters.

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Biotechnological Trends for Sustainability

Pravija Nitin Nikam, Meenu Devi and Shashidhara K. S.

Introduction

Biotechnology is a technology that utilizes biological systems, living organisms or their parts to develop, create or make various products. It is based on biology and can be considered a branch of biology. Although biotechnology is a contemporary hot word, it has been around for more than 6,000 years since mankind began to use the biological processes of microorganisms to make useful food products, such as bread, beer and cheese, and to preserve dairy products. The goal of sustainable agriculture is to provide population with food and fiber while protecting the environment and maintaining natural systems. To build sustainable climate-resilient agriculture, social and economic equality must be combined with economic viability and a healthy environment. In terms of crop enhancement, biotechnology has shown great promise in terms of yield, biotic and abiotic resistance, and nutrient-rich crops. Biotechnology is the application of scientific techniques to modify and improve plants, animals, and microorganisms to enhance their value (Arranz-Otaegui *et al*., 2018).

The two main functions of medicine are prevention of diseases and treatment of diseases and injuries, for both functions biotechnology has been playing an essential role and will play an even greater role in the future. An important step in diagnosing and treating infectious diseases is to detect and identify those microbes, fungi, mycoplasma, bacteria, chlamydia, virus and protozoans. Protozoology as well as sub-disciplines of microbiology such as bacteriology, mycology, and virology have been developed to study those microorganisms and protozoans. Early studies on bacteria usually involved growing bacteria on medium (bacterial culture) and dyeing them for observation and initial classification under microscope. Genetic testing can identify defective genes which underlie high morbidity of certain diseases in some families, thus allows the genetic diagnosis of vulnerabilities to inherited diseases (Katsanis and Katsanis, 2013). In a broader sense, it can test the possible presence of genetic diseases, or mutant forms of genes associated with increased risk of developing genetic disorders. The results of a genetic test can confirm or rule out a suspected genetic condition or help determine a person's chance of developing or passing on a genetic disorder.

Agricultural biotechnology is the area of bio-

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technology involving applications to agriculture. Agricultural biotechnology has been practiced for a long time, as people have sought to improve agriculturally important organisms by selection and breeding. An example of traditional agricultural biotechnology is the development of disease-resistant wheat varieties by cross-breeding different wheat types until the desired disease resistance was present in a resulting new variety. In order to increase crop productivity and resilience to different biotic and abiotic challenges, biotechnology is the technological application of biology. It mostly involves the transfer of genetic material containing a specific feature from one crop or organism to another (Hefferon, 2015). Numerous studies conducted on farms and small plots of land have shown that biotechnology intervention can enhance crop output, nutrient quality, and weed control while having no negative effects on the environment or ecosystem. Biotechnology has vast application than genetic engineering; it also includes genomics and bioinformatics. Biotechnology involves the use of approaches related to science to enhance the value of different kinds of living beings.

Biotechnology in medicine: Infectious diseases caused by pathogenic microbes and protozoans have been a serious threat to human health or even life. The earliest applications of biotechnology are vaccines and antiserums used to prevent and treat infectious diseases. Immunoassay and DNA/RNA detection are indispensable tools in diagnosis and detection of pathogens. Since developing new drugs from small molecules seems to become more difficult lately, more efforts have been put into researches on antibodies and DNA or RNA as therapeutic drugs by the pharmaceutical industry. Biotechnology contributes to the progress and success of medicine in the following areas:

- ✓ Providing new reagents, new methods and new drugs for the prevention, diagnosis and treatment of diseases
- ✓ Providing new materials for medical researches that advance our understanding of physiology, immunology, pathology of diseases and pharmacology of drugs, which in turn help develop new drugs, new vaccines and new treatments
- ✓ Making it possible to have personalized medicine and to cure by gene therapy those diseases that are inherited and caused by defective or mutated genes
- ✓ Making it possible to produce new biomaterials for treatment and transplantation that replace dysfunctional tissues and organs in the body.

Biotechnology in Agriculture

Through the improvement of crops with higher yields and fewer inputs, improved nutrition profiles or flavor, increased resistance to pests and herbicides, and decreased amounts of agricultural chemicals needed, biotechnology has significantly contributed to agricultural development.By crops and makes it easier to employ farming methods that are more ecologically friendly. The primary objectives of the three main goals of applying biotechnol-

ogy to agriculture are to: (1) boost crop yields; (2) enhance nutritional profiles and flavor and (3) minimize the use of pesticides and other chemicals, as well as labor and energy. The domestication of crops and livestock by early humans is actually a process of selective breeding. For thousands of years, humans have used selective breeding to improve the production of crops and livestock. In selective breeding, organisms with desirable characteristics are mated to produce offspring with the same characteristics which is strengthened each generation. This technique has produced sweet corns, fragrant rice, and chicken for laying more eggs as well as those growing fast to provide more meat, etc. Traditional breeding through hybridization has resulted in many crops with desirable characteristics such as high yield or resistance to diseases, pests, drought and saline soil. Hybrid rice strains play an important role in the fast growth of grain outputs in the past four decades in China. Genetic engineering can not only provide far greater control over genetic structure of plants and animals than previously afforded by methods such as selective breeding and mutation breeding, but also produce new strains with new traits that do not occur naturally in the species (Mittler & Blumwald, 2010). For example, a plant can be engineered to express a pesticide, thereby ending the need of external application of pesticides. The wide adoption of GM crops by farmers has caused concerns in some consumers and environmentalists. Environmentalists are concerned with invasion by GM crops to the natural flora. Consumers worry mainly about the safety of consuming GM food and some researchers have reported adverse effects in experimental animals fed on GM food.

Biotechnology in Livestock: The primary technique for producing a sufficient supply of food for the growing global population is biotechnology. Technological miracles include gender pre-selection in animals and cloning gene mapping techniques. Another view of germplasm cryopreservation as a technical gift is this one. It is said that the twenty-first century would be remembered as the century of molecular genetic markers and genomic selection. Methane production in cattle is made possible by biotechnology, and genetic selection increases milk production. The amount of biodiesel generated from various crop and animal waste feedstock's utilizing biotechnology processes. Enzyme-based biofuel synthesis is employed in biotechnology. It is favoured over chemical-based biofuel manufacturing.

Biotechnology in Industry: Application of biotechnology for preparing certain types of food and drink has a very long history. The making of wine, beer, cheese and many sauces for cooking involves fermentation processes, which were introduced in early Mesopotamia, Egypt, China and India. Modern industrial fermentation processes still use the same basic biological mechanisms. In brewing, starch (carbohydrates) from grains is converted into sugar by enzymes in malted grains and then into alcohol by added specific yeasts to produce beer. With a deeper

comprehension of industrial fermentation and microbiology, scientists and engineers looked for methods to enhance current production procedures and create new ones for producing goods other than food and beverages. Chaim Weizmann employed a pure microbiological culture for the first time in an industrial process in 1917 to use Clostridium acetobutylicum to make acetone from corn starch. The United Kingdom was in dire need of acetone to make explosives during World War I. In the years that followed, industrial fermentation was used to produce many non-food items, and it was also used to produce many antibiotics, including penicillin.

Bioinformatics: Bioinformatics is an interdisciplinary field that addresses biological problems using computational techniques to understand biological data. It may also be referred to as computational biology. Bioinformatics combines biology, computer science, information engineering, mathematics and statistics to analyze and interpret the biological data obtained from researches on structures and functions of nucleic acids, proteins, subcellular organelles, cellular organizations, and networks and systems as well as spatial structure of macromolecules. It plays an essential role in structural biology by assisting the simulation and modeling of DNA, RNA, proteins as well as bio-molecular interactions.

Role of Biotechnology in sustainability: The term "biotechnology" refers to a group of enabling technologies that can be used in a wide range of industrial industries. Genetic engineering, protein engineering, and metabolic engineering are the three separate domains of biotechnology. A fourth field, sometimes referred to as biochemical, bioprocess, or biotechnology engineering, is necessary for the commercial manufacture of biotechnology goods and provision of biotechnology services. None of the numerous different methods that biotechnology uses are applicable to every industrial area. Recognizing its strategic value, many countries are now formulating and implementing integrated plans for using biotechnology for industrial regeneration, job creation and social progress. Because of its versatility, biotechnology has been identified as a crucial technology for a chemical industry that is sustainable. Businesses that didn't think biological sciences would affect their operations are now looking into how biotechnology may help them. Biotechnology offers completely new possibilities for producing new and existing goods and services in a sustainable manner. The application of biotechnology in industry is motivated in part by environmental concerns, which aim to both prevent and eliminate contamination. In this context, biocatalyst-based processes play important roles.

Conclusion

The current status of biotechnology and its effects on the environment, economics, and human health have been examined in this article. Human society relies on biotechnology for everything from the domestication of crops and cattle to the manufacturing of beer, wine, cheese, and leavened bread, as well as for the development of vaccinations to prevent infectious diseases and antibiotics to cure

bacterial illnesses. Nearly all significant biotechnology discoveries and inventions result in quick commercial potential, and new businesses proliferate within that industry. What mankind wants to achieve with biotechnology is no more than getting methods and products to improve health and improve quality of life, which depends on better ability to biological processes and efficient application of such ability. With rapid progress in genetic engineering, we can expect that technologies to correct genetic defects and introduce preferred traits into the genomes will become conventional in treating human hereditary diseases and providing medicinal biologics for preventing and treating non-hereditary diseases by 2030.

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Schemes for Fisheries Development

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Introduction

Fisheries play an important role in the world economy and food for million. There are around 30 million fish farmers in the world which earn their livelihood from fisheries. Most of them are poor artisanal in developing countries. Globally, fish provide about 16 percent of the animal protein consumed by humans, and is a valuable source of minerals and essential fatty acids. Global fish production has grown steadily in the last five decades, with food fish supply increasing at an average annual rate of 3.2 per cent, outpacing world population growth at 1.6 per cent; with the result that the amount of fish available per person has increased. The stagnation of capture fisheries has been balanced by higher growth of aquaculture. The annual fish production increased from 65 million tonnes to 158 million tonnes between 1970 and 2012. The rapid growth of aquaculture contributed to overall fish production in the world. The global fish aquaculture production expanded from 32.4 million to 66.6 million tonnes with an average annual rate of 6.2 percent in the period 2000-2012 as compared to 9.5 percent in 1990-2000. Fish consumption has been steadily rising in tandem with the total increase in fish production. Fishery items and fish already capture the attention of People all throughout the world are concerned about their health. Because of its high Omega 3 fatty acid content, fish is more widely available in contemporary marketplaces. The year-round availability of various species and value-added forms is helping to satisfy the demands and desires of modern customers. All year long, aquaculture offers potential solutions to the range of items on the market. Additionally, value addition facilitates the transfer of regional specialties across national borders and lowers post-harvest losses. India has a rich freshwater fish diversity comprising of 1027 species in total (Gopi *et al*., 2017). Odisha water harbours about 186 species of fish, which represents approximately 18.11% of the total freshwater fish diversity in India (Mogalekar and Canciyal, 2018). Currently, India is the second largest fish producer with 8% global share in fish production. It also stands 2nd in aquaculture production, 3rd in marine capture fisheries and is one of the top shrimp-producing and exporting nations. India has been striving to improve the socioeconomic standing of fishers and fish farmers, boost exports, promote fish consumption, implement integrated

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management, maintain genetic variety and aquatic resources, and raise productivity and production in addition to creating jobs and revenue. The main strategy for reaching the export augmentation goal is to raise domestic postharvest and processing technology to international standards. The development of fisheries is dependent upon its surrounding policy and institutional framework, which includes legislation, administrative guidelines, organizations, services, infrastructural support, and incentives. Development and growth in fisheries are sustainable only with adequate support for training, extension, credit, skilled human resources and market infrastructure, which create the groundwork for increased productivity and competitiveness fisheries development and growth be achieved. The overall demand of fish for consumption is expected to be increased, with more and more people shifting their food habits towards protein rich diets. In India, 56% of the Indian population are fish eaters, and the per capita availability of fish is 9.85 Kg (Saha and Paul, 2020).

The Blue Revolution: Transforming India's fisheries sector: The concept of a "Blue Revolution" in India represents a paradigm shift in how we approach fisheries development. Just as the Green Revolution transformed agriculture in the 1960s, the Blue Revolution aims to revolutionize fish production and aquaculture practices across the country. This movement focuses on sustainable utilization of water resources for fisheries, emphasizing both marine and inland fishing activities.

The Blue Revolution encompasses various aspects of fisheries development, including modern fishing techniques, improved breeding practices, better storage and processing facilities, and enhanced market linkages. It recognizes that sustainable fisheries development requires a holistic approach that balances economic growth with environmental conservation and social welfare of fishing communities.

PM-MKSSY-Pradhan Mantri Matsya Kisan Samridhi Sah-Yojana: PM-MKSSY- is a central sector sub-scheme under Pradhan Mantri Matsya Sampada Yojana, launched on 8th February 2024 for a period of four years from FY 2023-24 to FY 2026 27. This scheme is implemented in all states and union territories with an estimated outlay of ₹6,000 crore, with ₹3,000 crore from GoI (₹1,125 crore loan from the World Bank, ₹375 crore loan from AFD and ₹1,500 crore as counterpart funding from PMMSY) and remaining ₹ 3,000 crore is expected to come from the private sector investment. With the aim of bringing institutional reform in fisheries sector in long term.

Aims and Objective of PM-MKSSY

- ✓ For better service delivery, the unorganized fishing industry will be gradually formalized

through the development of work-based digital IDs under the National Fisheries Digital Platform (NFDP).

- ✓ Granting fish farmers, fishermen, and micro and small businesses easier access to institutional financing, particularly operating cash.
- ✓ Providing 'one-time incentive' for one crop cycle to aquafarmers for purchasing aquaculture insurance.
- ✓ Incentivizing fisheries and aquaculture micro-enterprises through performance grants for improving fisheries sector value chain efficiencies including creation and maintenance of jobs.
- ✓ Incentivizing fisheries and aquaculture micro and small enterprises through performance grants for adoption ad expansion of fish and fishery products safety and quality assurance system including creation and maintenance of jobs.
- ✓ Integration and consolidation of fisheries value chains.

Implementing Agencies

- ✓ Department of Fisheries, Ministry of Fisheries, Animal Husbandry and Dairying, GoI.
- ✓ National Fisheries Development Board.
- ✓ Any other agency/ entity entrusted by the DoF, GoI.

PMMSY-Pradhan Mantri Matsya Sampada Yojana: As part of the Aatma Nirbhar Bharat Package, the Pradhan Mantri Matsya Sampada Yojana (PMMSY) was introduced on September 10, 2020, as a flagship program for the targeted and sustainable development of the nation's fisheries sector. It is expected to cost Rs. 20,050 crores to implement over a five-year period, from FY 2020-21 to FY 2024-25, in all States and Union Territories. PMMSY is intended to fill important gaps in the value chain of fisheries, ranging from technology, post-harvest infrastructure, and marketing to fish production, productivity, and quality. It seeks to ensure the socioeconomic well-being of fishermen and fish farmers while also modernizing and fortifying the value chain, improving traceability, and establishing a strong framework for fisheries management.

Objectives of PMMSY

- ✓ Harness the potential of the fisheries sector in a sustainable, responsible, inclusive and equitable manner.
- ✓ Enhance fish production and productivity through expansion, intensification, diversification and productive utilization of land and water.
- ✓ Modernize and strengthen the value chain including post-harvest management and quality improvement.
- ✓ Double fishers and fish farmers' incomes and generate meaningful employment.
- ✓ Enhance the contribution of the fisheries sector to Agricultural GVA and exports.
- ✓ Ensure social, physical and economic security for fishers and fish farmers.
- ✓ Build a robust fisheries management and regulatory framework.

Achievement of the scheme

- ✓ Increasing contribution of fisheries sector to the

Agriculture GVA to about 9% by 2024-25 from 7.28% in 2018-19.

- ✓ Doubling export earnings to Rs.1,00,000 crores by 2024-25 from Rs.46,589 crores in 2018-19.
- ✓ Reduction of post-harvest losses from the reported 20-25% to about 10.
- ✓ Facilitating private investment and growth of entrepreneurship in the fisheries sector.

National Scheme of Welfare of Fishermen

Announced in 1992, the program was formally ended by the Ministry of Fisheries, Animal Husbandry, and Diary's Department of Fisheries on March 31, 2020. This program was a component of the "Blue Revolution: Integrated Development and Management of Fisheries" centrally financed program. Its goal was to support small-scale fishermen. It was the centrally supported program that gives Indian fishermen financial support. The beneficiaries, who are fishermen both inland and offshore, can use the funds to build homes, community centers for recreation, and tube wells for drinking water.

Objectives of the Scheme

Enhancing Basic Amenities: Providing fishermen with essential amenities such as housing, community halls, and access to clean drinking water through tube wells.

Improved Living Standards: Elevating the standard of living of fishermen and their communities.

Skill Development: Educating and training fishermen in advanced fishing technologies and scientific methods.

Financial and Social Security: Ensuring the financial and social well-being of fishermen and their families.

Conclusion

To encourage entrepreneurship, boost productivity and establish a strong and sustainable fishing industry, the Indian government has introduced a number of initiatives. The programs, which range from infrastructure development and financial assistance to value chain modernization and talent development, are designed to help the fishing industry reach a long-term, self-sustaining growth trajectory. At the heart of these initiatives is the government's dedication to enhancing the socio-economic circumstances for fishermen and growing India's market share in international fisheries. By implementing these plans, India hopes to lead the world in the development of sustainable fisheries, guaranteeing economic growth, improved livelihoods and food security.

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Fruits as a Source of Natural Food Colours 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, chlorophyll will leave wavelengths that constitute a green color because its highest absorbencies are at 430 and 680 nm. A mixture of leftover wavelengths frequently produces the colors; for instance, anthocyaninsm 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 pigmentation 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. 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.

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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 anti-inflammatory 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 betacyanins-have been shown to possess neuroprotective, anti-inflammatory, and anti-cancer qualities. Although 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 cardiovascular 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 degeneration.

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, anthocyanins, 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.

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.

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Advancing Seed Research through Cutting-Edge Technologies

Rajeeb Lochan Moharana, Chandan Kumar Shadangi and Kumar Avinash Biswal

Introduction

As part of Agriculture 4.0, technologies like artificial intelligence, nanotechnology, and the Internet of Things are becoming more and more common. It greatly impacted agricultural and value chains and revolutionized the industrial process. To improve output quality and create pest-resistant seeds, the farming sector is implementing smart breeding technologies, genome editing, a mix of digital AI-based technologies, and microbial soil mapping. One of the main ideas in IoT security is data flow monitoring using encryption techniques. This is accomplished by employing AI-based security tools to instantly recognize warning signs of dubious activity and by storing data on the blockchain to guarantee its integrity. Farming has experienced several technological revolutions in recent decades, becoming increasingly industrialized and technology-driven. Farmers now have more control over crop development and yield because to the use of clever agricultural technology and animal productivity, increasing their predictability and efficiency. Together with an increase in consumer demand for agricultural products, this has accelerated the global adoption of smart farming technologies. The sector 4.0 movement is set to have a significant impact on the industry thanks to its revolutionary energy. Along with collaboration, mobility, and open innovation, the campaign is based on a number of digital technologies and habits, including big data, artificial intelligence, and the Internet of Things. The advent of modern agriculture has brought forth challenges and opportunities to innovate and enhance the field. One of the significant aspects of this transformation has been the focus on seed quality enhancement (Gough, 2020). Seeds are, quite literally, the kernels of life that sprout into plants, providing food, fiber, and a multitude of other resources essential for human survival. According to Afzal *et al*. (2023), seeds are extraordinary biological entities with the rare capacity to produce new plant generations. A seed's quality dictates how likely it is to sprout and develop into a robust, healthy plant under a variety of field conditions. By making it possible to create high-yield, stress-resistant crop types that can flourish in a variety of dynamic climates, advanced seed technologies present a feasible alternative. From conventional breeding to innovative biotechnological integration, the development of seed technology has greatly improved agricultural sustainability and productivity. The seed industry has been greatly impacted by recent develo-

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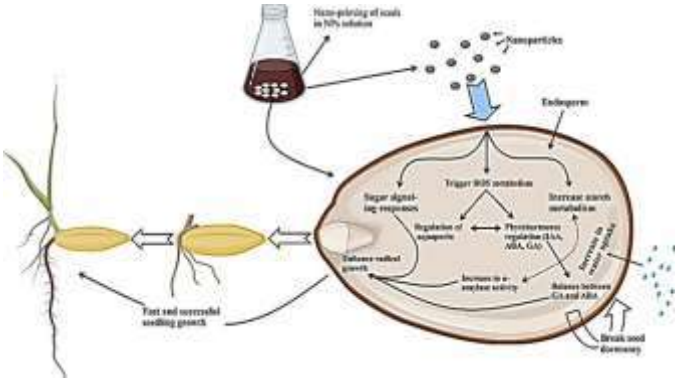
pments in biotechnology, which have led to creative ways to increase agricultural output beyond what was previously thought possible. The significant effects of biotechnological developments on Indian agriculture demonstrate how incorporating state-of-the-art biotechnologies can revolutionize farming methods and usher in a new age. Biotechnological tools such as genetic engineering, marker-assisted selection (MAS), tissue culture, and genome editing play a crucial role in enhancing seed traits. In addition to this, seed treatment methods, when tailored to specific objectives and crop types, play an important role in achieving optimal stand establishment and enhancing yields, especially under varying climatic conditions.

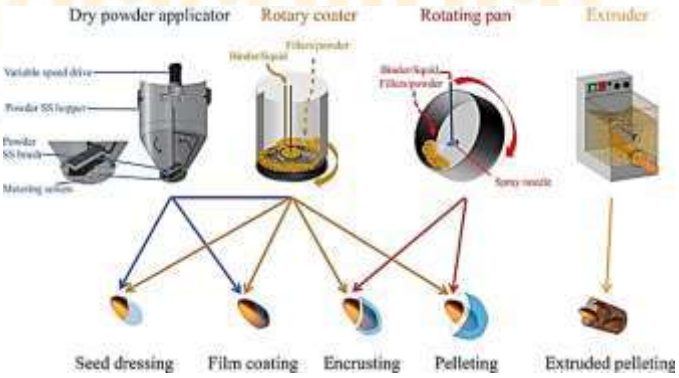
Innovative techniques in Seed Technology

Genetic Engineering and Transgenic Seeds: The utilization of genetic engineering for modification of the seeds represents a significant rise forward in the pursuit of agricultural innovation, particularly in India, where agriculture plays a pivotal role on the basis of both the economy and the well-being of most of the people. This approach entails directly altering an organism's genetic composition to impart specific traits, including increased yield, resistance to pests and diseases, and improved nutritional value Sharma *et al*. (2002). Genetic engineering allows for precision gene manipulation inside a plant's DNA, enabling targeted insertions, deletions, or alterations of the desired genes, as opposed to traditional breeding approaches that rely on the process of natural genetic diversity. Genetic engineering not only advances the creation of better crop types but also makes it possible to introduce characteristics that are not present in the species naturally. Transgenic seed production uses a variety of complex techniques, each of which modifies the genetic composition of plants in a unique way. Among other strategies, recombinant DNA technology was the first and most popular way to introduce desired genes from other countries into plant genomes (Liu *et al*., 2013). The process of gene silencing, facilitated by approaches like RNA interference (RNAi), represents an alternative strategy employed to inhibit the expression of unfavorable characteristics, such as vulnerability to diseases or inadequate nutritional quality, through the precise targeting and inactivation of particular genes. The methodologies have collectively broadened the scope for enhancing crops, providing more effective, precise, and adaptable methods for creating transgenic seeds. In India, the initiation of transgenic crops commenced with Bt cotton, which stands as the excellent instance of genetically reformed agriculture in the nation.



Seed coating material: The technique of seed coating involves enveloping the seed in a protective

layer with the goal of improving seed handling, increasing seed visibility while planting, and immediately delivering the nutrients, insecticides, or growth-promoting agents that are required to the seed environment. In order to maximize seed performance and guarantee good crop output, this method is essential to contemporary agricultural techniques. Recent advancements in coating materials have been predominantly emphasized on the exploration and development of biodegradable polymers, super-absorbent polymers, and nano-materials. These materials are designed to provide specific benefits such as targeted nutrient release, increased water retention capabilities, as well as heightened protection mechanisms against a variety of pests and diseases. The novel coatings are engineered to degrade once their purpose is served, thereby reducing their impact on the environment. The formation of these resources demonstrates a profound comprehension of seed physiology and interactions between soil and plants, designed to facilitate the process of seed germination and initial seedling growth in different agricultural environments (Hadas, 2004). Inoculation, priming, pelleting, and seed film coating are common seed treatment techniques used worldwide. The purpose of these procedures is to increase the seeds' capacity for plantability, dissemination, germination, and storage. Biological agents, fungicides, herbicides, sticky films, and growth promoters are applied using a variety of methods. Chemical compounds are used in the seed coating procedure to aid in the development of seedlings. To improve overall seed performance, growth regulators, inoculants, micro-nutrients, fungicides, insecticides, and other seed protectants are applied to the seed pellet. Film formulations containing commercially available plasticizers, polymers, and colorants are commonly used for this purpose. The specific composition of the coating material is typically kept confidential by the companies developing them. Generally, the coating material comprises binders, fillers (such as polyvinyl alcohol, gypsum, and clay), and an intermediate layer (e.g., clay, polyvinyl acetate, and vermiculite). Seed agglomeration represents an alternative coating technology that allows for the simultaneous sowing of multiple seeds from the same lot, or of different lots, varieties, or species.



Nanotechnology for the advancement of seed: Nanotechnology, the deliberate control of materials at the level of atoms or molecules, has surfaced as a fundamentally altering influence in multiple fields, such as agriculture, presenting fresh remedies to critical issues encountered by the sector. In India, agriculture plays an important position in both the economic as well as societal welfare, thereby highlighting the significance of integrating nanotech-

nology with the seed advancement and agricultural practices to improve productivity, sustainability, and adaptation to climate variations (Pramanik *et al*., 2020). In particular, the use of nanotechnology in seed improvement aims to change how seeds are tended to, protected, and monitored, enabling them to withstand biological and environmental stresses more successfully and maximizing their genetic potential for quality and productivity. Seed nano-priming can provide a protective mechanism for plants against various biotic and abiotic stresses, particularly PTEs stress, owing to the distinctive physico-chemical properties of nanoparticles. Furthermore, depending on the dosage, nano-particles' biological effects on plant growth and yield might vary, showing both positive and negative consequences. In the agricultural industry around the world, nanoparticles have been widely used as Nanofertilizer to increase the yield and growth of a variety of crops and to compensate for plant deficits in vital nutrients. The application of Nano-encapsulation of pesticides and fertilizers for seed treatment is one of the most common applications of nanotechnology in the agriculture industry. This tactic includes enclosing vital nutrients or protective substances in nanoscale carriers that can be designed to release their contents in a controlled way or in response to certain environmental stimuli.

Conclusion

The scrutiny of biotechnological advance-ments in seed technology offers a substantial opportunity to enhance the agricultural sector in India, with the prospective to improve crop productivity, sustainability and resilience. India encounters various challenges as it maneuvers through the intricacies of incorporating sophisticated genetic engineering, molecular breeding, and nanotechnology in its agricultural methodologies. These challenges primarily stem from regulatory structures, intellectual property rights, ethical dilemmas, and societal attitudes towards these advancements. Nevertheless, the possible ecological and socio-economic advantages, such as enhanced harvest productivity, minimized use of chemical inputs as well as improved climate change adjustment, emphasize the significance of these technologies.

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Lawn Grasses in the Garden

Rohan Tomar and Ajay Baldaniya

Introduction

Globalization and urbanization are the major drivers of the worldwide homogenization of urban landscapes. The flora and fauna of cities in different parts of the world are strikingly similar, despite geographical and climate differences (Muller and Werner, 2010). In most of the Western world, urban landscapes have been influenced and shaped by the same land scape few architectural approaches, namely French formal, English Picturesque and Victorian Gardenesque and, in the 20th and 21^{s}t century, Modernism (Ignatieva, 2010). A lawn can be defined as the green carpet for a landscape. It is an important feature for any type of garden. In a home garden a lawn improves the appearance of the house, enhances its beauty and increases convenience and usefulness. The lawn provides a perfect setting for a flower bed, a border, a shrubbery, specimen tree or a shrub. Besides the material value, a lawn has its spiritual value too. A lawn is the source of charm and pride and reduces tension of the mind after a day's hard work in the materialistic world. The lawn is one of the most potent representations of various landscape architectural styles and consequently, of contemporary urban landscapes (Stewart *et al*., 2009). Regardless of their purpose or location within the city, only a small number of management strategies have been chosen for urban lawns. In today's world, the use of lawns is considered a byproduct of our way of life. Nowadays, up to 70-75 percent of all green open spaces in cities are lawns. They can be found along roads, at golf courses, cemeteries, public parks, and private gardens. Without examining their social, ecological, or aesthetic values, the majority of Westerners consider lawns to be a "natural" and even required part of the urban landscape. There is a common positive view of lawns as functional and accessible areas in parks, playgrounds and private gardens. Lawns often have symbolic value and people enjoy them (see, hear, smell etc.), although they may be not permitted to enter or use the lawn area. However, the intensive management practices used on lawns, such as frequent mowing and spraying of herbicides and fertilizer's, has raised awareness about their potential negative impact on the urban environment. The lawn serves to enhance the beauty of the garden. Maintaining the right loan plays a crucial role in any landscape design. A beautiful, well-groomed lawn can make the whole landscape look beautiful but when the lawn is not maintained the beauty of the landscape inevitably deteriorates. 60-75% of any

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Table 1: Common Grass species used for lawn making

Botanical Name	Common name	Texture	Suitable Location
Cynodon dactylon	Hariyali (or) Doob grass	Medium	Suitable for open sunny locations; drought; tolerant
Stenotaphrum secundatum	St. Augustine grass	Coarse	Suitable for shady situations; requires frequent watering
Pennisetum clandestinum	Kikiyu grass	Rough	Grow well in acids soils, suitable for higher elevations.
Sporobolus tremulus	Chain Grass	Fine	Suitable for saline soils and open sunny locations
Poa pratensis	Blue grass	Medium	Suitable for acid soils and suitable for higher elevations
Zoysia japonica	Japan grass	Coarse	Can grow well in poor sandy soil; open sunny situations
Zoysia matrella	Manila grass	Medium	Suitable for open sunny situation
Zoysia tenuifolia	Korean grass or velvet grass	Fine	Suitable for open sunny situation
Cynodon sp.	Bermuda grass (or) Hyderabad grass	Fine	Suitable for open sunny situations
Paspalum vaginatum	Paspalum grass	Medium	Suitable for open sunny situations
Festuca sp.	Fescue grass	Coarse	Shade tolerant, survive on inferior soils
Cynodon sp.	Dwarf Bermuda	Medium	Suitable for open sunny situations

garden should be dedicated to loan. The lawn is also useful as a playing surface as it reduces ground erosion and dust generated due to the foot pressure of many players. The lawn also serves as a cushion for players in sports such as football, soccer, cricket, baseball, golf, tennis and hockey.

Planting methods of Lawn

By seeds: The earliest and most well-known approach is this one. This approach is used across vast regions or overseas. Only in situations when grass roots are unavailable should lawn be produced from seed. It takes three to five weeks for seeds to germinate. It takes about 25-30 kg of seeds to sow one hectare.

Turfing: This is the fastest and most expensive way to grow a loan. Turfs should be cut evenly into squares where the grass is short, compact and free from weeds. This turf should be placed on the prepared ground site and beaten side-by side with a turf beater. The middle cavity should be filled with fine clay. The entire turf area should be rolled and irrigated.

Dibbling of Roots: This approach is time consuming but inexpensive. Small portions of grass roots should be sown 10-15 cm deep in flat terrain when it becomes wet after rain. Following seeding, the soil needs to be compacted. The roots grow underground and disperse over around six months. A reasonably compact lawn is one that is regularly moved, rolled, and irrigated.

Turf plastering: This approach isn't very helpful in arid and dry regions. This allows for the free collection of a significant amount of submerged grass and the appropriate cutting of 5-7 cm into both long and short pieces. Two baskets of cut grass

should be well combined with a basket of fresh garden soil, a basket of fresh cow dung, a shovel of wood ash, and the necessary amount of water. After that, the mixture is watered from a can and evenly distributed over the previously wet, fully layered surface to a minimum thickness of 2.5 cm. The following day, the grass should be given time to spread out and the earth should be rolled up. In this manner, the grass grows in roughly two weeks.

Astro Turf: This particular kind of artificial lawn is often utilized in playgrounds and on rooftops in developed countries. A crucial stage in giving the grass a uniform surface is the constant water spraying, which bonds the synthetic fibers.

Conclusion

Everyone needs to take some time each day to relax amid the hectic and stressful times of today. Sitting on the grass brings joy to the mind and helps one forget about the day's concerns. Growing a grass in your home garden, which is actually simple and entertaining, is also a status symbol these days. You have the freedom to choose whether or not you want free, peaceful oxygen delivery from your house.

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Ethnobotany, Pharmacology and Phytochemistry of *Ficus concinna* (Miq.)

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Introduction

The plant kingdom has long served as an invaluable source of both ecological stability and medicinal compounds, offering solutions to a myriad of environmental challenges and human health concerns. Within this vast kingdom, the genus *Ficus* (family:Moraceae) stands as a particularly remarkable and diverse group, comprising over 880 species distributed predominantly across tropical and subtropical regions worldwide (Sasidharan *et al*., 2023). Figs are crucial to the environment and have cultural significance. Because of their asynchronous fruiting, which offers a consistent year-round food source for a wide variety of frugivores, they are frequently referred to as "keystone species" and help to sustain and preserve biodiversity in their environments. Their unique ecological and evolutionary relevance is further highlighted by their intricate mutualistic association with fig wasps for pollination. Among the many species within this ecologically important genus, *Ficus concinna* (Miq.) Miq. which is commonly known as the Red Leaf Fig or Drooping Fig, stands out as a notable tree native to a wide geographical area, extending from India and Bangladesh to southern China, Myanmar, Thailand, Vietnam and Borneo.

In India, *F. concinna* is found across several regions, including the Andaman Islands, Assam, Bihar, Jharkhand, Madhya Pradesh, Meghalaya, Odisha, Sikkim, and West Bengal (Karthigeyan and Jayanthi, 2016). *Ficus concinna* (Miq.) Miq., also referred to as the Red Leaf Fig or Drooping Fig, is a noteworthy tree that is native to a large geographic area that includes southern China, Myanmar, Thailand, Vietnam, and Borneo, among the many species that make up this ecologically significant genus. The Andaman Islands, Assam, Bihar, Jharkhand, Madhya Pradesh, Meghalaya, Odisha, Sikkim, and West Bengal are among the Indian states where *F. concinna* is found. According to the literature, there wasn't as much research done on medicinal values. For *F. concinna* in particular, scientific confirmation of these claims and a thorough comprehension of the underlying pharmacological mechanisms are still lacking despite its extensive traditional use. Ficus species generally appear to contain a broad range of bioactive substances, such as flavonoids, terpenoids, phenolic acids, alkaloids, saponins, and steroids, according to preliminary phytochemical screenings.

Morphology: It is a tall tree up to 25-30 m high. The branchlets are terete, smooth, and hairless (glabrous),

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Table 1: Ficus species used as food and medicine

Botanical name	Local name	Use(s)
Ficus amplissima	Indian bat tree	Fruits are edible; they are consumed by birds; their juice is used to treat mouth ulcers.
Ficus arnottiana	Paras pipal	The root of the plant is used as an astringent.
Ficus auriculata	Roxburgh fig	Fruit is used as a vegetable; fruit is used to treat diabetes.
Ficus benghalensis	Banyan	The latex is applied to treat tooth decay.
Ficus benjamina	Weeping fig	Latex from fruit extracts is used to treat piles.
Ficus concinna	Baidimri	Stem is chewed to get relief from toothache
Ficus drupacea	Brown woolly fig	Root powder is mixed with oil of *Pongamia pinnata* and applied externally to cure skin infections
Ficus elastica	Rubber fig	The fruit pulp is used for digestive problems.
Ficus exasperata	Sandpaper tree	The bark and root decoction are used against cough.
Ficus hederaceae	Climbing fig	NIL
Ficus heterophylla	Bada dimri	Bark powder is mixed with mustard oil and boiled. The filtered oil is applied to microbial infections.
Ficus hispida	Dimiri	The fruit is edible; the bark decoction is used to treat fever and colds.
Ficus mollis	Soft fig	The tender leaves are consumed as a preventive agent against diabetes.
Ficus nervosa	Sanadimri	Latex is used to reduce gum problems
Ficus palmata	Wild fig	Grounded leaves and fruits are combined with herbal tea to combat diabetes.
Ficus racemosa	Dimbri	Fruits are used as a vegetable; fruits are also used to treat leucorrhea
Ficus religiosa	Pipal	Bark of *Ficus religiosa* and fruits of *Syzygium cumini* are boiled in water and the extract is used to treat diabetes
Ficus rumphii	Variegated rumph's fig	Formulations are prepared with leaves of *Ficus rumphii*, *Ocimum sanctum*, *Moringa oleifera*, and *Marsilea minuta*. The juice of the formulated powder is used to treat sleeping disorders and to improve immunity.
Ficus semicordata	Bhuin dimri	The paste of Bark is mixed with leaves of *Curcuma longa* and applied on leach bites
Ficus tinctoria	Kharsara	Fruits are edible; fruits are used against indigestion
Ficus virens	White fig	Tender leaves and fruits are grounded and the juice is taken against diabetes.

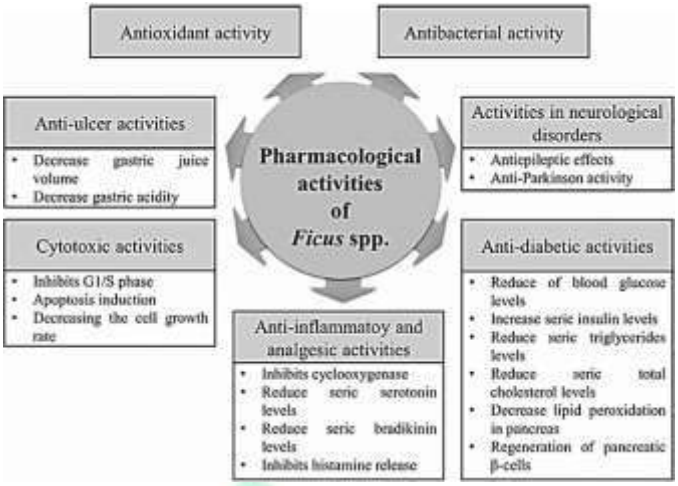
with sparse lenticels. The leaves are simple and arranged alternately. They are narrowly elliptic to oblong-elliptic or ovate in shape, with bases that range from rounded to wedge-shaped (cuneate). The leaf margins are entire (smooth, without teeth), dark green and glossy on the upper surface, and pale on the underside. Both surfaces are glabrous and coriaceous. There are 9-10 pairs of lateral veins, and the midrib is canaliculated on the upper side. The petiole is glabrous and measures 1-2.1 cm in length and 2.1-2.4 mm in width. The stipules are ovate, 7-9 mm long and 3-5 mm wide, tapering to a long point (long acuminate), hairless, and fall off early (caducous).

Ecological Significance: The ecological value of numerous Ficus species is widely recognized. It is a keystone species in many habitats, offering vital resources to a diverse array of fauna and making a substantial contribution to biodiversity. Its significance in preserving the resilience and health of ecosystems is further highlighted by its capacity to flourish in a variety of settings and its function in ecological succession. By serving as a food source for a variety of fauna and adapting to a range of environmental situations, *Ficus concinna* serves as a keystone species in the ecosystem, making a substantial contribution to biodiversity and ecosystem health. Numerous bird species, including the orange-headed thrush and red-whiskered bulbul, were found to eat figs of *F. concinna* during the field

investigation (Kumar *et al*., 2022).

Pharmacological activities: Plants are typically rich in diverse antioxidant compounds, which contribute to most of their biological effects in the human system. Antioxidants can inhibit oxidation via termination of radical reaction by donating at least one hydrogen atom to the free radical or by preventing the initiation of radical chain reaction via a substitutive reaction. Due to their numerous pharmacological effects, Ficus species are employed in both traditional and modern medicine to treat a variety of illnesses. Recent research has demonstrated the therapeutic effectiveness of Ficus species, particularly in conditions affecting the central nervous system, heart, and lungs.

Anti-microbial activity: One of the most important medical advances in the fight against microorganisms was the creation of antibiotics. However, these may have unwanted side effects include allergies, digestive issues, or the development of antibiotic-resistant bacteria. Numerous studies over the past few decades have shown that natural alternatives have antibacterial qualities, raising the prospect of reducing antibiotic resistance and substituting safer antibiotics derived from natural sources. These substitute natural antibiotics work by either (a) preventing the growth of bacteria through ostatic mechanisms or (b) destroying the germs entirely through bactericidal mechanisms. An ethanolic leaves extract from *F. religiosa* was able to inhibit the in-vitro growth of several bacteria, namely, *Enterococcus faecalis, Shigella flexneri, Proteus vulgaris, Staphylococcus saprophyticus, Shigella dysenteriae* and *Shigella sonnie* with a minimum inhibitory.



Anti-diabetic activity: Diabetes is a complex syndrome induced by the disorder of insulin secretion by the beta cells of pancreas or by the resistance of peripheral cells to the action of insulin. The most known effect of these dis orders is to increase the blood glucose level above the limits considered normal-hyperglycemia. The antihiperglicemic efficacy of Ficus plants has been demonstated by many experimental studies. A recent study demon strated that the next doses 100, 200 mg/kg of an aqueous extract from F. religiosa leaves administered orally decreased the fasting blood glucose in streptozotocin (STZ) induced type-2 diabetic rats. This extract contains flavonoids, phytosterols, tannins and furanocoumarin derivatives like bergapten and bergaptol (Swami and Bisht, 1996).

Anti-inflammatory and analgesic activity: Inflammation is the most important nonspecific defense mechanism of the body against the aggression

produced by inflammatory agents such as pathogens, chemicals or physical injury. Various phyto-constituents have the potential to interfere with the mechanisms and combat a series of inflammation. One of the mechanisms that involves inflammation is an injury to the skin and other soft tissues, and the wound healing process. An inflammatory response occurs upon injury that subsequently induces the cells underlying the dermis layer to increase collagen production, followed by epithelial tissue regeneration in response to healing (Kokkas, 2010). Swiss albino mice were used to assess the analgesic effects of *F. benghalensis* aqueous root extract at doses of 100 and 200 mg/kg. The hot-plate, tail-flick, and writhing tests are a few of the tests that are conducted. An important finding was noted in the writhing test after being treated with the root extract, suggesting that the plant root may have analgesic properties (Panday and Rauniar, 2016).

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Collaboration with Artificial Intelligence (AI) in Horticulture Science

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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 development of computer systems that can carry out tasks that traditionally require human intelligence is called artificial intelligence (AI).

AI is pervading horticulture and used increasingly in academia and industry, with diverse applications from plant breeding to robotic crop harvesting and augmentation of grower and agronomist decision support. AI technologies remain the foundational digital enabler of robotics and autonomous systems, and are likely to be a key feature of horticultural crop production (Duckett *et al*., 2018).

Due to reduced availability and development of synthetic herbicides, AI enabled weeding machines are now entering mainstream commerce. These systems built upon camera guided mechanical weeders that originally deployed conventional machine vision. 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. The field of computer science known as artificial intelligence (AI), also referred to as machine intelligence, teaches machines how to mimic human physical movements and respond in human-like ways. The term ‘Artificial Intelligence’ was coined by John McCarthy in 1950. How come artificial intelligence? It is viewed as a chance, particularly in challenging circumstances or issues that standard computing systems and humans are unable to adequately resolve. It has many uses in the horticulture sector. Machines may frequently be made to perform tasks more effectively than people,

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including planting, watering, and harvesting as well as testing new systems. In order to increase yield, the horticulture sector needs workers with expertise in artificial intelligence. Artificial intelligence (AI) technologies help produce healthier crops, provide information on current weather conditions, such as temperature, rain, wind speed, wind direction, solar radiation, pest control, and soil and growing conditions, organize data for farmers, lessen their workload, and enhance the food supply chain (Manaware, 2020). A recent turning point in AI that has received a lot of attention is the development of high quality deep neural networks, or simply deep learning (DL) frameworks, which are a type of MLs. The concept and basic systems of DL were established in the 1980s. The recent focus on DL has been its high accuracy in image classification following the development of a convolutional neural net- work (CNN) named AlexNet, which won the ImageNet Large Scale Visual Recognition Challenge (ILSVC) 2012 (Krizhevsky *et al*., 2012). DLs differ from traditional machine learning in that they consist of multiple layers and can automatically learn complex features and characteristics from large datasets (Janiesch *et al*., 2021). CNN is a frame of DLs applied to convolutional layers that can extract local features while considering translation invariance by applying sliding filters called kernels to the input data.

Advantages of AI in Horticulture

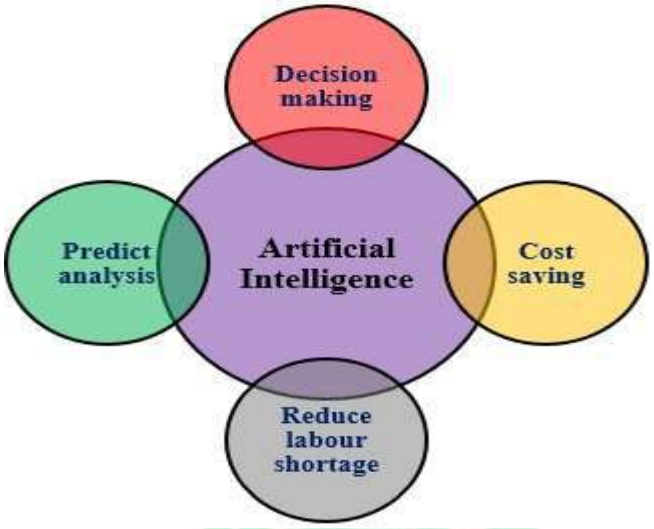
- ✓ AI provides more efficient ways to produce, harvest and sell essential crops.
- ✓ AI implementation emphasis on checking defective crops and improving the potential for healthy crop production.
- ✓ The growth in AI technology has strengthened agro-based businesses to run more efficiently.
- ✓ Used in applications such as automated machine adjustments for weather forecasting and disease or pest identification.
- ✓ AI can improve crop management practices.
- ✓ AI solutions have the potential to solve the challenges farmers face such as climate variation, an infestation of pests and weeds that reduces yields.
- ✓ It wouldn't eliminate jobs of human farmers rather it will improve their processes.

Applications of AI in Horticulture

Produce maturity identification: It is necessary to photograph different crops in white or UV-A light in order to determine the stage of fruit maturity. Farmers may create several maturity grades according to the crop or fruit category and arrange them in distinct stacks before to sending them to the market, especially for highly perishable horticultural items. Post-harvest shelf life would also be increased by harvesting at the proper maturity.

Image-based insight generation: One of the most contentious aspects of farming in the modern world is precision farming. Drone imaging can help with thorough field analysis, crop monitoring, and field scanning. Drone data, IoT, and computer vision technologies will work together to make sure farmers respond quickly. Data fed from drone image could

bring forth alerts in real time which would accelerate precision farming.



Weather & Price Forecasting: Many times it is difficult for the farmers to make the right decision for harvesting, sowing seeds, and soli preparing due to climate change. But with the help of AI weather forecasting, farmers can have information on weather analysis, and accordingly, they can plan for the type of crop to grow seeds to sow and harvest the crop. Price forecasting helps farmers maximize their profit by providing them with precise information about crop prices for the upcoming few weeks.

Health Monitoring of Crops: The crop quality widely depends on the soil type and nutrition of the soil. Various factors degrading the soil quality day by day and it is hard to determine it. To resolve this issue, AI based mobile application Plantix was developed to identify deficiencies in soil, including plant pests and diseases. With the help of this application, farmers can get an idea to use better fertilizer to improve the harvest quality.

Intelligent Spraying: AI sensors enable the rapid detection of weeds and the identification of areas impacted by weed growth. Herbicides can be accurately sprayed in these locations to minimize the need for herbicides while also saving time and crop damage. AI sprayers can cut down on the amount of chemicals applied to fields, enhancing crop quality and resulting in cost savings.

Disease Diagnosis: Plant leaf images are segmented into surface areas such as background, diseased area, and non-diseased area of the leaf thanks to image sensing and analysis. After that, the unhealthy or infected region is clipped and sent to the lab for additional testing. This provides further support in identifying pests and detecting dietary deficiencies.

Artificial intelligence and protected cultivation: Greenhouse production processes are already highly automated and controlled but, similar to what is occurring in many sectors, AI systems are now taking control to unprecedented levels. Because of their potential ability to process large amounts of data and make tiny continuous adjustments, AI systems are beginning to provide greenhouse operators with myriads of production-related benefits. In protected horticulture, artificial intelligence (AI) can forecast production, guarantee product quality from raw materials to harvest, assist

in determining the best time-to-market and resource allocation, and boost productivity. As a result, it can support farmers' financial gain and the sustainability of their output. Both play a significant role in industrialized production processes that have vast greenhouse compartments spread across multiple locations, a shortage of competent labor, and a rise in the demand for expensive food near cities. Furthermore, the relationship between growing circumstances and shelf-life processes must be clarified so that feedback from the end point consumer acceptance can be utilized to modify growing conditions.

Artificial intelligence for crop physiology performance: Plant physiological processes are crucial for crop monitoring, second only to plant morphology. Important biochemicals including sugars, starches, chlorophyll, and nutrients are produced by photosynthesis in the leaves during crop development and are then transmitted to the plant's organs, flowers, and fruits (Dharmaraj and Vijayanand, 2018). Therefore, measuring the efficiency of plant photosynthesis directly and non-destructively is a desirable way for obtaining information on crop performance and for the early detection of deviations from optimal physiological conditions. Technologies like chlorophyll fluorescence imaging and thermal imaging are promising, especially if they can be applied to other parts of crop canopies, as well as individual leaves.

Fruit picking robots: When collecting fruits, the robots have to be careful not to damage the leaves or branches of the tree. Every portion of the tree that is being harvested needs to be accessible to robots. With the use of video image capture, the robot is able to differentiate between fruits and greenery. The robot arm's camera recognizes colors and compares them to characteristics that are stored in memory. The fruit is collected if a match is discovered. Use an air jet to remove foliage in order to reveal concealed fruit. The fruit is removed off the tree by the pressure applied to it, but it does not crash. The sort of fruit being plucked affects the gripper form.

Conclusion

In addition to helping farmers automate their processes, artificial intelligence in horticulture also enables more accurate cultivation for higher crop yields and higher quality while using fewer resources. Labor is a major expense in gardening. A substantially higher competent labor force is needed for intensive horticultural crops than for large-scale farming. More than half of production costs are related to hiring labor for different jobs. AI can help you manage labor costs, apply fertilizers and pesticides efficiently, and minimize crop losses by harvesting crops at the proper time. Farmers can reduce production costs and increase production capacity with the use of artificial intelligence (AI).

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Mealworms: A Tomorrow's Diets

Saras

Introduction

The word 'Entomophagy' is composed of two Greek words i.e. "Entomos" meaning insects and "Phagein" meaning food. Thus, entomophagy refers to the practice of eating insects. Insects are eaten by humans as food for over a thousand years since the time of hunters and gatherers and this practice continues for several years with subsequent civilization. Entomophagy has a long history in human evolution (Fontaneto *et al*., 2011). Insects provide various advantages to the ecosystem and human well-being. Over 2100 species are available as food. Greeks and Romans ate locusts and caterpillars. Out of the million recorded insect species, over 2141 species are edible and are traditionally consumed as food by some ethnic communities, especially in Africa, Asia, Australia, and Latin America (Mitsuhashi, 2016). The famous Greek philosopher wrote about the harvesting of sweet cicadas and the new covenant describes how St John the Baptist survived honeybee and locusts in the deep desert. It is fascinating to note that more than two billion people eat insects on a regular basis, accounting for a major amount of animal protein consumption in some regions (Van Huis *et al*., 2013). Insect farming particularly of species like *Tenebrio molitor* (mealworms) provides environmental advantages, requiring less land and water and emitting fewer greenhouse gases. Challenges remain, especially in consumer acceptance, which can be improved by processing insects into flour or powder forms. With growing regulatory support, including the approval of *T. molitor* as a novel food, insect protein presents promising potential for sustainable nutrition and diverse food industry applications. Invertebrates, like insects, make up 95% of the animal kingdom but have not gotten much attention as a food source despite having nutritional content similar to cattle. Because insect farming consumes less water, land, deforestation, and greenhouse gas emissions, it has a far smaller environmental impact. However, because entomophagy is often associated with disease or disgust, consumer acceptance remains the largest barrier. Making flour or protein powder from insects can increase their acceptability. Additionally, supportive laws are relevant. For example, the first insect to be approved as a novel food for human consumption was *Tenebrio molitor*. According to Bovera *et al*. (2016), insects in general and mealworm can be used as a replacement of soya-bean meal in the diets of chickens without affecting growth and diet palatability. There are three species of mealworm: *Tenebrio molitor* L. (yellow mealworm), *Zophobas atratus* (giant mealworm) and *Alphitobius diaperinus* panzer (lesser mealworm). Mealworms are the larval stage of Coleoptera

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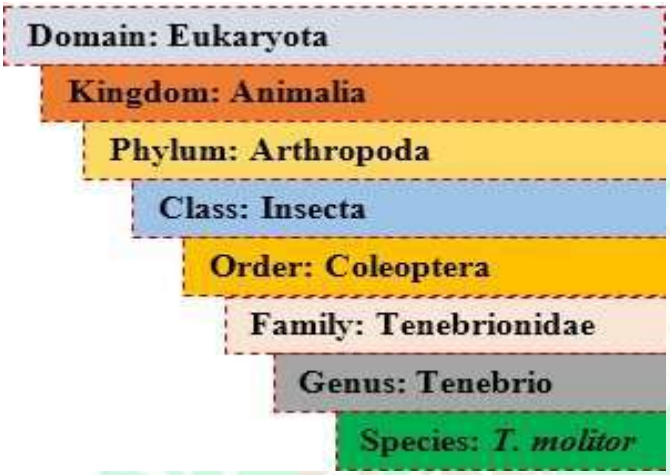
Tenebrionidae (darkling beetles). Mealworms are a harmful pest of stored grains; however, its larvae are commonly used as pet food in many countries. According to Li *et al*. (2013), mealworm can also be used in a bio-regenerative life support system in space, by providing an efficient system for treating plant waste and providing protein for Astronauts. Mealworms are considered as potential ingredients for fish diet Rainbow trout.

Taxonomic Position of Mealworm

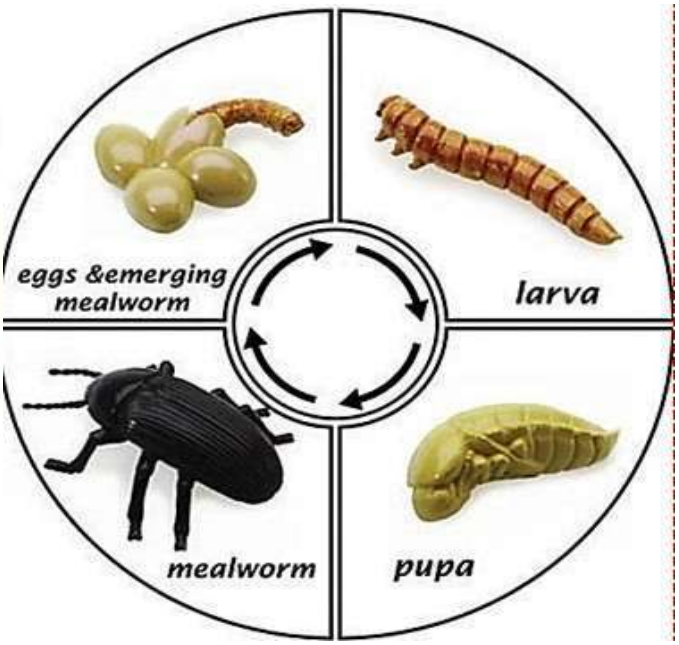


The biology and lifecycle of mealworms

The life cycle of mealworms has four stages: adult darkling beetles lay eggs, tiny larvae emerge from eggs and larval stage begins, the larva turns into pupa before it becomes an adult beetle. The entire process takes place in the same ecosystem. The environmental conditions such as diet, relative humidity, temperature and population density are key factors that con tribute to the developmental stages of darkling beetle mealworm.

Eggs: The incubation period of eggs varies between periods of 4days at 26-30 °C and 34 days at 15 °C.

Larvae: The tiny larvae emerge from the eggs and the larval stage begins. Mealworm larval stage goes through instar stages where the old skin is removed by a new one; the process can take 17 instars before it becomes a pupa. During this process, the body length gradually increases with each successive instar. The larvae of the yellow mealworm are white with the first instar; it gradually turns brown after the 2nd instar. After the larval stage, the larvae begin a short period of inactivity gaining a "C" shape before turning into a pupa, the process which is called metamorphosis. A larva is a good source of protein for chickens and other captive animals.



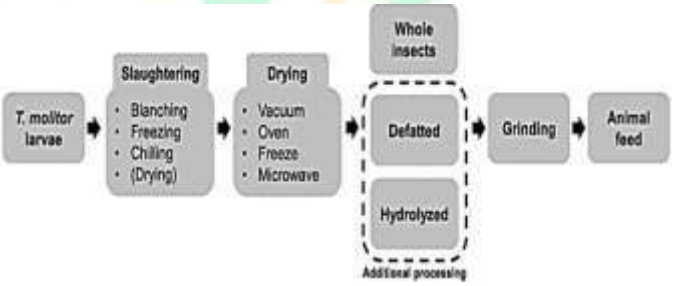
Pupa: The pupa has no mouth or anus so does not eat; it continuously turns its helpless body. The duration of the pupal stage varies between 6 and 20 days before it becomes a beetle.

Adult: *T. molitor* is a species of the Tenebrionidae family, commonly known as darkling beetles. The adult darkling beetle female lay an average of 400-500 eggs in a substrate at the bottom of the container where they are bred (Spencer and Spencer 2006).

Nutritional value of mealworms

Mealworms' nutritional value varies according to their species and stage of development. Protein, lipids, vital amino acids, and vitamins and minerals are all abundant in these worms. Generally speaking, insects have lower levels of the amino acids methionine and cysteine but larger levels of lysine and threonine, which are lacking in the most widely consumed cereals, wheat, rice, cassava, and maize. The excreta and exuvium components were shown to have the highest levels of calcium when compared to the larva and beetle, despite the fact that mealworm larvae are likewise low sources of calcium but rich in phosphorus. Chickens fed only mealworms may develop metabolic bone disease symptoms and a calcium deficit. As a result, when using mealworms, calcium supplementation is advised. *T.molitor* contains a high amount of protein, fats, amino acids and mineral content ; as a result, it can easily be included in the poultry ration. Khan *et al*. (2017) reported that mealworms are the best insect meal option as compared to maggot and silkworm; they improve broiler performance and meat quality. The concentration of elements such as calcium (Ca), copper (Cu), iron (Fe), potassium (K), magnesium (Mg), manganese (Mn), sodium (Na), phosphorus (P), Sulphur (S), strontium (Sr) and zinc (Zn) plays a critical role during the metamorphosis stages of mealworms.

Extraction process of *T. molitor*: According to the International Platform of Insects for Food and Feed (IPIFF), post-slaughtering (drying and grinding) and slaughtering (heating or freezing) processes are commonly used to process insects for animal feed. These steps are crucial for maintaining the nutritional composition as well as for guaranteeing safety. Blanching, freezing, chilling, and drying are steps in the slaughtering process. To kill vegetative cells and stop microbial growth during storage, Vandeweyer *et al*. (2020) Recommended blanching before chilling or drying. Because *T. molitor* larvae have a high moisture content, drying is crucial after slaughter. The moisture content of T. molitor larvae is approximately 68%. This high moisture level may lead to microbiological spoiling and enzymatic or non-enzymatic deterioration. Consequently, it is advised to have a moisture level of 4 to 5% to prevent any issues.



Extraction of Lipid: The process of removing lipids for use as feed additives and to improve the digestion of proteins is known as defatting. Although there are other methods for defatting, the most widely used one uses a Soxhlet device using organic solvents like hexane, petroleum ether, or ethanol, in which the particles and solvent are constantly in touch. In the Soxhlet technique, the mixture is condensed in cool tubes, and when the solvents have evaporated, the lipids are measured.

Conclusion

A key component of poultry diets, protein

serves a variety of essential functions, including maintaining and mending tissues to support organism growth and development. The most dependable, simple-to-breed insects that are high in protein and satisfy the amino acid needs of cattle are mealworms. There is already industrial production of mealworms. Therefore, small-scale poultry producers can benefit from the same methods employed by commercial mealworm farmers by having specialized Agricultural Extension officers (entomologists) step in. But a low-cost production technique that would satisfy the demands of impoverished farmers in rural areas needs to be created. Addressing consumer hesitancy, improving processing technologies, and encouraging regulatory support are essential.

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Public Health Programs in India

Saras and Puneet Mohan

Introduction

Age old definition of health given by WHO states that, "Health is a state of complete physical, mental and social well-being and not merely the absence of disease". Medicine or curative services is not the only soul contributor to health and well-being of population. There are several other determinants of health which include environmental, biological, socio-economic factors, information and communication, availability of health services, utilization of health services, age structure of the population etc. By influencing these elements or determinants, we could significantly contribute to better health. A community's health can be protected and improved through the art and science of public health, which is coordinated and methodical endeavor that covers public health services, education, and shielding the public from harmful exposures. India's public health sector has witnessed considerable growth over the years due to various public health programs aimed at addressing its diverse health challenges. From tackling infectious diseases to improving maternal and child health, these initiatives have played a pivotal role in improving the health outcomes of the country's vast population. Despite these strides, the country still grapples with a dual burden of communicable and non-communicable diseases, and public health programs remain crucial to addressing these challenges. A robust health system is necessary if the Sustainable Development Goals (SDGs) are to be achieved. It is also central to designing, implementing and monitoring health programmes; delivering quality health services; and ensuring universal health coverage (Hazarika, 2013). Strong health systems will need adequate and well-trained health professionals, and a shortage of health workforce can often be a crucial limiting factor in the delivery of quality health services in low- and middle-income countries. Public health is a vital part of any health system and is ultimately responsible for reducing health risks and maintaining and improving health status. Consequently, as noted in a United States of America (USA) Institute of Medicine report, public health professionals play a pivotal role in the creation and maintenance of a healthy community (Gebbie *et al*., 2003). For its vast population, a developing country like India must make plans for sufficient access to high-quality healthcare. It is acknowledged that public health education in the nation needs to be started and properly strengthened.

Major Public Health Programs in India

National Health Mission (NHM): The National

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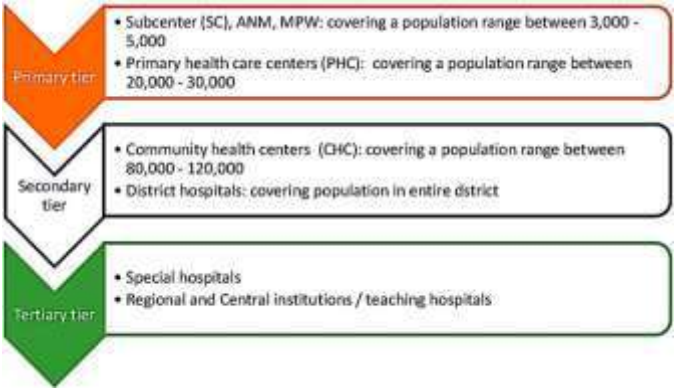
Rural Health Mission (NRHM), now under National Health Mission is an initiative undertaken by the government of India to address the health needs of under-served rural areas. Launched on 12 April 2005 by then Indian Prime Minister Manmohan Singh, the NRHM was initially tasked with addressing the health needs of 18 states that had been identified as having weak public health indicators. The Union Cabinet headed by Manmohan Singh vide its decision dated 1 May 2013, has approved the launch of National Urban Health Mission (NUHM) as a Sub-mission of an overarching National Health Mission (NHM), with National Rural Health Mission (NRHM) being the other Sub-mission of National Health Mission.

Key Achievements of NHM

- ✓ Maternal mortality ration declined by 83% since 1990.
- ✓ Total fertility rate dropped from 2.3 (2015) to 2.0 (2020).
- ✓ Tuberculosis (TB) incidence reduced from 237 per 1,00,000 population (2015) to 195 (2023). The mortality rate decreased from 28 to 22 (2015-2023).
- ✓ Malaria cases and deaths declined by 13.28% and 3.22% respectively, in 2021 compared to 2020.
- ✓ Sickle cell anemia screened over 61 crore individuals under the national sickle cell elimination mission launched in 2023.

Ayushman Bharat Pradhan Mantri Jan Arogya Yojana (AB PM-JAY): Ayushman Bharat Pradhan Mantri Jan Arogya Yojana (PM-JAY; lit. 'Prime Minister's People's Health Scheme', Ayushman Bharat PM-JAY lit. 'Live Long India Prime Minister's People's Health Scheme'), also colloquially known as Modicare. It is a national public health insurance scheme of the Government of India that aims to provide free access to health insurance coverage for low income earners in the country. Roughly, the bottom 50% of the country qualifies for this scheme. It was later expanded to include all citizens aged 70 years and above, regardless of their economic status. It was launched in September 2018 by Prime Minister Narendra Modi. Offering health coverage to 10 crore households or 50 crore Indians, PM-JAY features include: ₹5 lakh (or ₹5.6 lakh or US$6,600 in 2023) per family annually for medical treatment in public and private hospitals that have been accredited; allowing cashless payment and paperless recordkeeping through the hospital or doctor's office; and determining eligibility for benefits based on criteria from the Socio Economic and Caste Census 2011.



Pulse Polio Immunization Program: In India, the Expanded Programme on Immunization (EPI) began polio vaccine in 1972. By 1999, it had administered three doses of OPV to almost 60% of babies.

The Universal Immunization Programme (UIP) was introduced in 1985 with the goal of vaccinating every area in the nation. UIP joined the Reproductive and Child Health Program in 1997 after first joining the Child Survival and Safe Motherhood Program in 1992. This initiative resulted in a notable 5% increase in coverage. Additionally, the number of polio cases reported decreased from thousands in 1987 to 42 in 2010. India started the Pulse Polio immunization program with the Universal Immunization Program in 1995 in response to the World Health Organization's Global Polio Eradication Initiative, with the goal of achieving 100% coverage.

National Aids Control Program (NACP): The AIDS Control Program in India is widely seen as a triumph. In India, a comprehensive program for HIV/AIDS prevention and control is being carried out under the National AIDS Control Programme (NACP), which was introduced in 1992. Raising awareness has given way to behavior change over time, as has the national response to a more decentralized one and the growing participation of NGOs and PLHIV networks.

Mission Indradhanush: Launched in 2014, Mission Indradhanush aims to increase immunization coverage by reaching out to children and pregnant women who have been left out of routine immunization programs.

Swachh Bharat Mission (SBM): The WHO reports about 600 million episodes of diarrhoea and 400,000 childhood deaths a year due to contaminated water and lack of sanitation, with an estimated 80% of all diseases and one third of all deaths in developing countries induced by consumption of contaminated water (Rajgire, 2013). Government report in May 2017, claims that over two lakh villages have become open defecation free (Dash, 2016). However, urban areas struggle to manage their daily municipal waste and open urination. In rural areas, the challenge is the liquid waste generated. Shirking responsibilities of those responsible and inadequate facilities to process solid waste remain big challenges for this flagship programme. The government of India launched the Swachh Bharat Mission (SBM), also known as the Swachh Bharat Abhiyan or Clean India Mission, on October 2, 2014, with the goal of eradicating open defecation, enhancing solid waste management, and establishing Open Defecation Free (ODF) communities. Additionally, the program seeks to raise awareness of managing menstruation health. It is a modified form of the Nirmal Bharat Abhiyan, which the Indian government introduced in 2009. The official name of the campaign is in Hindi. It means “Clean India Mission” in English. Prime Minister Narendra Modi of India formally inaugurated the campaign on October 2, 2014, in Rajghat, New Delhi.

Positive Impacts of Public Health Programs

Eradication of Polio: The Pulse Polio Immunization Program has been a resounding success, leading to the certification of India as polio-free in 2014 by the World Health Organization (WHO). The program’s extensive outreach and high coverage ensured the

successful eradication of the disease.

Improved Immunization Coverage: Mission Indradhanush has been instrumental in improving the country's immunization rates. It targets children in hard-to reach areas and has significantly increased immunization coverage from 62% in 2014 to nearly 90% in recent years. This has played a crucial role in reducing vaccine-preventable diseases like measles, diphtheria and tetanus.

Reduction in Maternal and Child Mortality: Programs under the National Health Mission, such as Janani Suraksha Yojana (JSY) and Janani Shishu Suraksha Karyakram (JSSK), have contributed to a significant reduction in maternal and child mortality. The Maternal Mortality Ratio (MMR) has decreased from 130 per 100,000 live births in 2014-16 to 97 in 2018-2020. Similarly, the Infant Mortality Rate (IMR) has seen a decline due to better healthcare facilities and improved immunization coverage.

Access to Affordable Healthcare: Ayushman Bharat's PM-JAY scheme has enhanced access to secondary and tertiary healthcare for millions of poor and vulnerable families. By covering hospitalizations for major diseases and surgical procedures, the program has reduced the financial burden on families, particularly in rural areas.

HIV/AIDS control: The National AIDS Control Program has successfully curtailed the spread of HIV. India has seen a 66% reduction in new HIV infections and a 54% decline in AIDS-related deaths between 2000 and 2021. The program's focus on awareness campaigns, preventive measures and free antiretroviral therapy (ART) has saved countless lives.

Sanitation and Hygiene: Swachh Bharat Abhiyan has improved sanitation infrastructure across the country. The program's success in eliminating open defecation and constructing over 100 million toilets has had a positive impact on reducing water borne diseases like diarrhoea, especially in rural areas. Improved hygiene practices have also contributed to better health outcomes in terms of infection control.

Progress in Tuberculosis Control: The National Tuberculosis Elimination Program (NTEP) has led to significant improvements in TB detection and treatment. India's TB notification rates have improved and the country's aggressive TB management strategies, including free diagnosis and treatment, have contributed to a steady decline in TB-related deaths.

The way forward to strengthen health systems in India:

Retain focus on increasing government investment on health: In the years ahead, the universal implementation of two components of 'Ayushman Bharat Program' would require approx. Rs.70-100 thousand Crore (US$ 11.5 - 15.5 billion) per annum. This higher health investment would be consistent with the NHP-2017 goal of the government allocating 2.5% of GDP to health by 2025. This would necessitate a 20–25% yearly rise in financial distribution made by the federal and state governments. Fiscally deficit governments may use the promise of giving cash as needed and not allocating

enough to the already underfunded health sector as a "perverse incentive" to delay implement-ation. A better method than comparing nominal amounts or budget to budget estimates is to measure government spending on health as a percentage of GDP.

Strengthen and scale up ongoing initiatives: Numerous ongoing initiatives, such as expanding services for non-communicable diseases, strengthening referral links at all facility levels, scaling up services in urban areas, and providing free medicines and diagnostics, are complementary and should continue to be prioritized. Certain metropolitan regions frequently have lower health results than rural ones, and the urban population also suffers other issues such air pollution, a lack of public space for physical activity, overcrowding, and migrant populations, all of which increase health risks.

Establish institutional mechanism to bring stakeholders together: Interaction with civil society organizations and the community will be essential. Accountability, continuity, quick initiative scaling, and putting health on the election agenda are all possible outcomes of this. As knowledge partners, academic and research institutions can assist in developing local solutions while continuing to learn from best practices and global experience as needed.

Conclusion

In India, public health initiatives have significantly improved the health of millions of people, particularly in the areas of lowering the prevalence of communicable diseases, enhancing the health of mothers and children, and increasing access to healthcare through insurance programs. But issues like poor infrastructure, unequal access to healthcare, and the growing prevalence of NCDs necessitate fresh initiatives to fortify the healthcare system. India can advance its goal of universal health coverage and better public health outcomes for all of its population by tackling these issues and expanding on the achievements of current initiatives.

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Nutritional and Therapeutic Potential of *Alianthus excelsa*

Suneha Rani, Sahil Sharma and Ankita Singh

Introduction

During the past decade, the indigenous or traditional system has gained importance in the field of medicine. In most of the developing countries, a large number of populations depend on the traditional practitioners, who are dependent on medicinal plants to meet their primary health care needs. Although, modern medicines are available, herbal medicine retained their image for historical and cultural reasons. Since the usage of these herbal medicines has increased, issues and moto regarding their quality, safety and efficacy in industrialized and developing countries are cropped up. Increasing interest has forced researcher to screen scientifically various traditional claims. There is need of screening the traditional claims because this is scientific era and everyone wants the scientific support before using the traditional drugs. So presently both common user and health care professionals seek updated, alterative information towards safety and effect of any recommended medicinal plants as drug prior to its use. *Ailanthus* is a genus of tall, leafy trees, widely distributed in Indo-Malay, Japan, China and Australia. The genus is noted for its antidysentric and antidiarrheal properties. Different species of the genus are *Ailanthus glandulosa* in China and Malay Peninsula, (leaflets very coarsely toothed at the base and filaments several times exceeding the anther), *Ailanthus malbarica* in Indo-China (leaflets entire and filaments larger than anther) and *Ailanthus excelsa* in India (leaflets very coarsely toothed and filaments shorter than anther) (Lavhale and Mishra, 2007). *Ailanthus excelsa* Roxb. resemblance with the neem tree (*Azadirachita indica*) and Maharukha due to its large size. The plant is known by different names like tree of heaven in English, and other Indian local names are as. *Ailanthus excelsa* Roxb. Is known by different name such as Araluka, Aralu, Katvanga, Deerghavrinta, Putiveriksha and Maha-neem. The tree is indigenous to central and southern India and is found across Madhya Pradesh in Panchmahal and Bharuch districts in Gujarat, some coastal districts in Andhra Pradesh, Ganjam and Puri districts in Orissa. It also grows in Sri Lanka, Japan, China, and Australia. It occurs in dry deciduous forests. It can be seen planted along the roadsides. The tree is known for its high economic and commercial importance. *Ailanthus excelsa* Roxb

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largely occurs in Rajasthan and central India and grows throughout the tropical and sub-tropical climatic conditions of the country, especially in dry tracts. It grows well in arid, semi-arid, and semi moist regions of India. It grows well in regions with rainfall < 500 mm. The tree was found planted on riverine and Sandy soil. It is commonly found in mixed deciduous forests and some sal forests with heavy monsoons conditions. It grows at an altitude of 0-900 m with annual temperature of 0-45 °C. Moreover, the stem bark of this plant is considered as a substitute for *Holarrhena antidysenterica* in treating dysentery (Dhanasekaran *et al*., 1993). The Nilgiri tribes of India utilize its bark as antifertility medicine. Furthermore, pharmacological studies revealed its potential as an antileukemic, antifungal, antibacterial antifertility and antimalarial agent (Tariq *et al*., 2017).

Taxonomical classification	
Kingdom	Plantae
Phylum	Magnoliophyta
Class	Magnoliopsida
Order	Sapindales
Family	Simaroubaceae
Genus	*Ailanthus*
Species	*Ailanthus excelsa*

Ethno pharmacology of *Ailanthus excelsa* Roxb.:

In Chinese system of medicine bark of *A. excelsa* is used to treat diarrhea and dysentery, especially when there is a blood in stool (Dash and Padhy, 2006). *Ailanthus excelsa* is a fast growing tree and is extensively cultivated in many parts of India in the vicinity of villages; it is cultivated as an avenue tree for its deep shade and can be used for ant-erosion purposes. The bark has been used in Asian and Australian medicine to counteract worms, excessive vaginal discharge, malaria and asthma. It has marked antispasmodic and cardiac depressant properties. The root bark is used to cure epilepsy and heart troubles. Traditionally the mattress made of leaves is used as bed for children suffering from fever. In Bombay the bark and leaves are of great repute as a tonic especially in debility after child birth. They are used in dyspepsia, bronchitis and asthma. In Konkan the juice of the leaves is usually administered in khir, or the juice of the fresh bark is given with coconut juice and treacle or with aromatics or honey to stop after pains. It is also used to cure wounds and skin eruptions. The plant is used as natural antifertility agent by the Irula women in Mavanahalla region of the Nilgiri district in Tamil Nadu. The fresh juice of stem bark mixed with either honey or sugar is given to pregnant woman during evening for three consecutive days to induce permanent sterility.

The bark is used as bitter, refrigerant, astringent, appetizer, anthelmintic, febrifuge, in dysentery, earache, skin disease, troubles of the rectum and fever due to tridosha and allay thirst. It is also used in gout and rheumatism. In Ayurveda it is used to remove the bad taste of mouth. Fruits are used in

diarrhea, polyurea, piles and fever. Leaves along with twigs are found to be suitable fodder for cattle, sheep and goats. The tree yields an inferior quality of bassora or hog gum. The plant acts as one of the host for silk worms. The tree is grown in France for its leaves, which are fed to the caterpillar of the silk-spinning Ailanthus moth (*Bombyx Cynthia*), producing silk that is more affordable and durable than mulberry silk. In the process of making paper, the short-fibered wood is mixed with long-fiber pulp, such bamboo pulp. Additionally, it is employed in the pencil-making process. The bark has several properties, including being astringent, bitter, anthelmintic, febrifuge, appetizer, bitter tonic, and stimulating the taste buds. Diarrhea, dyspepsia, amoebic dysentery, anorectal illness, chronic giardiasis, hemorrhoids, fistula, fissures, ulcerative colitis, and worm infection might all benefit from it. Additionally, it is utilized as a blood purifier for all skin conditions, including boils, carbuncles, scadies, gouty arthritis, typhoid fevers, blood coagulation issues, and skin infections.

Pharmacological properties

Antifungal activity: Chloroform fraction of the ethanol extract of stem bark showed significant fungistatic and fungicidal activity against *Aspergillus fumigatus, Penicillium requentence, Aspergillus niger, Penicillium notatum* and *Botrytis cinerea* (Lavhale and Mishra, 2007).

Antimalarial activity: The revelation that a number of quassinoids have strong antimalarial properties, particularly against the chloroquine-resistant *Plasmodium falciparum,* has been hailed as a major breakthrough. It was discovered that even at a concentration of 0.2 RM, excelsin inhibited the proliferation of malarial parasites. Glaucarubinone inhibits the synthesis of proteins in both malaria parasites and mammalian cells, making it far more effective than chloroquine. It has been proposed that their amoebicidal action is likewise explained by this effect. All quassinoids inhibits protein synthesis more rapidly than nucleic acid synthesis in the *P. falciparum* infected human erythrocytes which is mainly due to its effects upon ribosome rather than upon nucleic acid metabolism.

Anti-amoebic activity: *Ailanthus excelsa* stem bark's anti-amoebic properties in vitro. Using metronidazole as a reference medication, the anti-amoebic activity of *Ailanthus excelsa* stem bark extracts in aqueous, petroleum ether, and defatted ethanolic fraction (*Quassinoid fraction*) was evaluated against laboratory-cultured Entamoeba histolytica. According to Yoganandam *et al*. (2009), the EC values against *E. histolytica* for aqueous, petroleum ether, and defatted 50 1 ethanolic extracts (Quassinoid fraction) were 195, 185, and 150 µg mLG, respectively.

Anti-bacterial Activity: Ethyl acetate fraction of dried stem bark inhibited the growth of *Staphylococcus aureus, Escherichia coli*, and *Bacillus subtilis* (MIC: 6 mg disc^{-1}). Three active principles, excelsin, 13, 18-dihydroexcelsin and 1, 12- deoxy-13-formylailanthinol, isolated from bark, are said to be responsible for this activity.

The antibacterial activity of all three compounds was more pronounced than the antifungal potency.

Gastroprotective and Antisecretory Activity: The pretreatment of animals with methanolic, petroleum ether and chloroformic extracts (100 mg kg^{-1}, oral (p.o.)) from *A. excelsa* significantly reduced gastric lesion induced by ulcerogenic agent (56, 47, and 70%, respectively) when compared with animals pretreated with vehicle. However, the diethyl ether pretreatment led to the least gastric lesion damage (83%), similar to the standard antiulcer drug, cimetidine, at the same dose (100 mg kg^{-1}, p.o.). The lower effective dose of diethyl ether extract, as well as cimetidine, given by the intraduodenal route, significantly increased the pH values and reduced the acid output of gastric juice. Sterols, triterpenes, and quassinoids are present in the diethyl ether extract of *A. excelsa* stem bark, which presented the best gastroprotective action among the studied extracts. Our study confirmed the traditional indications of *A. excelsa* for the treatment of gastric ulcers.

Conclusion

Herbal medications and plants derived from natural resources have once again gained prominence globally in recent years for preserving people's health. Serious questions concerning the quality, safety, and effectiveness of natural sources and plant-derived products have grown as a result of their widespread use worldwide. The tree Ailanthus excelsa Roxb, also called the tree of heaven, is a member of the Simaroubaceous family and is native to central, southern, and Sri Lankan regions.

It contributes to the body of knowledge and natural scientific resources. The tree has a number of medical applications because of its gum, bitter, aromatic leaves, and stem bark, all of which are said to have therapeutic qualities.

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Carbon Sequestration for Climate Resilience

Sowmya M., Nazreenbanu Tahasildar and Rashmi S.

Introduction

The pursuit of ever-increasing food production by humans has an impact on the environment. As analysts long feared, soil degradation in all its forms is not a precursor to mass hunger. However, it is decreasing crop yields and causing malnutrition in many parts of the world. The potential improvement in production is not realized despite the availability of superior cultivars with enhanced yield potential due to inadequate management of the crop system (Reynolds and Tuberosa, 2008). The soil resource base has been gradually deteriorating due to the ongoing use of conventional farming methods that involve heavy tillage, particularly when combined with in situ burning of crop wastes (Montgomery, 2007). Conservation tillage is a widely used term to characterize the development of new crop production technologies that are normally associated with some degree of tillage reductions, for both pre-plant as well as in-season mechanical weed control operations that may result in some level of crop residue retention on the soil surface. Climate change, largely driven by anthropogenic GHG emissions, particularly CO_2, poses a serious threat to global ecological balance, food security, and human well-being. As per the IPCC's Sixth Assessment Report, global temperatures have risen by approximately 1.1°C above pre-industrial levels, with dire consequences projected if temperatures rise beyond 1.5°C. One promising response to this crisis is carbon sequestration-capturing atmospheric CO_2 and storing it in vegetation, soil, oceans, or geological formations. Carbon sequestration is a key component of sustainable development since it not only helps to slow down climate change but also increases ecosystem resilience. Its incorporation into land-use practices, particularly in forestry and agriculture, offers the double advantages of improving livelihoods and mitigating climate change, particularly in developing nations like India. The physics, technology, and socioeconomic ramifications of carbon sequestration are covered in detail in this work.

How is Carbon Sequestered in Soils?

Izaurralde *et al*. (2007) defined carbon sequestration as implementation of a land management practice that increased net primary productivity, reduced rate of heterotrophic respiration or both and lead to an increase in ecosystem C

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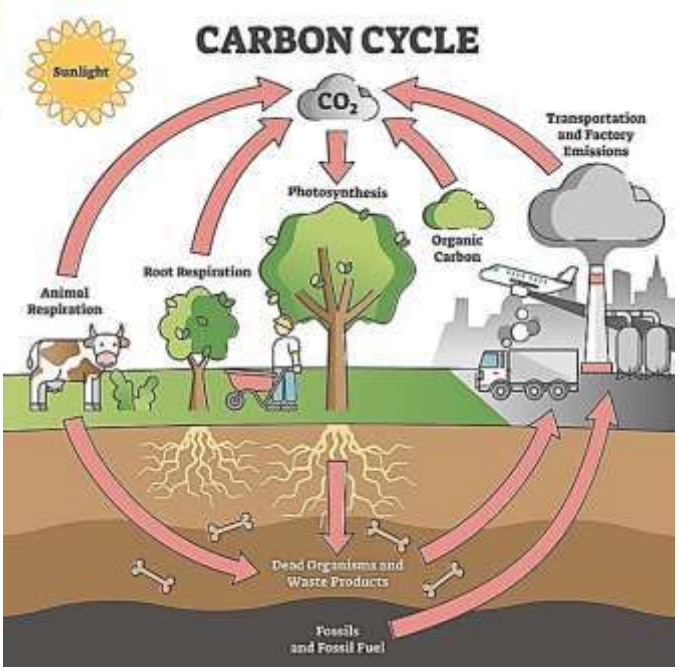
storage. Planting trees, reducing the intensity of tillage on cropland, or restoring grasslands on degraded lands will all lead to an increase in C storage in plants, soils, or both. Through the process of photosynthesis, plants assimilate carbon and return some of it to the atmosphere through respiration. The carbon that remains as plant tissue is then consumed by animals or added to the soil as litter when plants die and decompose. The primary way that carbon is stored in the soil is as soil organic matter (SOM). SOM is a complex mixture of carbon compounds, consisting of decomposing plant and animal tissue, microbes (protozoa, nematodes, fungi, and bacteria), and carbon associated with soil minerals. Carbon can remain stored in soils for millennia, or be quickly released back into the atmosphere. Climatic conditions, natural vegetation, soil texture, and drainage all affect the amount and length of time carbon is stored. Carbon can either remain stored in soils for millennia, or quickly released back into the atmosphere. Climatic conditions, natural vegetation, soil texture, and drainage all affect the amount and length of time carbon is stored in soil.

Management techniques for carbon sequestration in soils

Conservation agriculture: Conservation agriculture (CA) is defined as minimal soil disturbance (no-till) and permanent soil cover (mulch) combined with rotations. It is a more sustainable cultivation system for the future than those presently practiced. According to Food and Agricultural Organizations (FAO) of the United Nations, conservation agriculture is defined as a concept for resource saving of agricultural crop production that strives to achieve acceptable profits together with high and sustained production levels while concurrently conserving the environment and minimizing or eliminating manipulation of the soil for crop production. Conservation agriculture has a proven potential of converting many soils from source of C to sinks of atmosphere C by sequestering it into soil (Lal *et al.*, 1998). It improves agriculture by reducing erosion, increasing water infiltration, improving soil surface aggregates, reducing compaction through promotion of biological tillage, increasing surface soil organic matter and carbon content, moderating soil temperatures, and suppressing weeds.

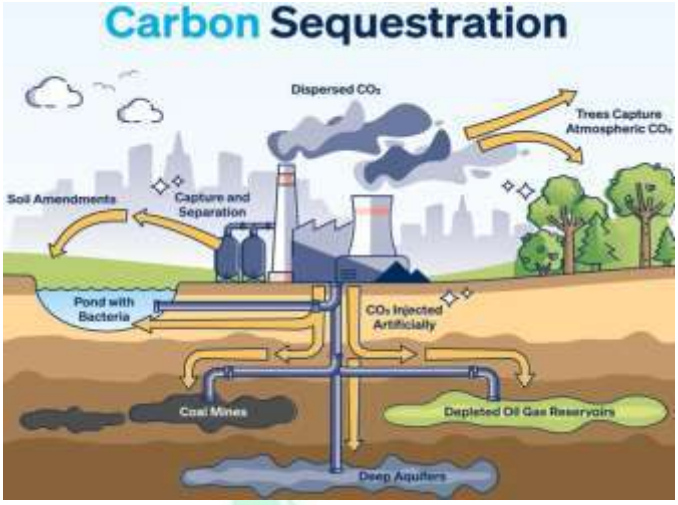


Minimum/zero tillage: The main purpose of tillage is to provide favourable soil environment for plant growth. It is one of the major factors responsible for reducing carbon stocks in soil.SOM is oxidized when

it is exposed to the air by tillage, resulting in a reduction in organic matter (OM) content, unless additional OM is returned to the soil as residues, compost, or other means. Tillage disrupts the pores left by roots and microbial activity. The effect of this on below ground biology is not well known. The primary reason for the loss of carbon from soil is believed to be the use of disc harrows and mould board ploughs, which break up soil aggregates and hasten the decomposition of plant waste. C sequestration in agricultural soils could result from modifications to tillage techniques. Mulch tillage, minimal tillage, and no tillage are all examples of conservation tillage.

Cover crops: Cover crop is the use of crops such as legumes and small grains for protection and soil improvement between periods of regular crop production. Cover crops improve carbon sequestration by enhancing soil structure and adding organic matter to the soil.

Crop rotations or crop sequencing: Crop rotation is a sequence of crops grown in recurring succession on the same area of land. It improves the soil structure and fertility by alternating deep rooted and shallow rooted plants. A crop that leaches one kind of nutrient from the soil is followed during the next growing season by a dissimilar crop that returns that nutrient to the soil or draw different ratio of nutrients. Varying the type of crops grown can increase the level of soil organic matter. However, effectiveness of crop rotation depends on the type of crops and crop rotation times. The main component of crop rotation is replenishment of nitrogen through the use of green manure in sequence with cereals and other crops.



Benefits of Carbon Sequestration

Climate Resilience: Carbon sequestration mitigates climate change by lowering atmospheric CO_2 levels and contributes to stabilizing weather patterns, reducing the incidence of droughts, floods, and temperature extremes.

Soil Health and Fertility: Increasing soil organic matter improves soil structure, nutrient availability, and water retention-essential for sustainable crop production and climate-resilient agriculture.

Biodiversity Conservation: Forests, wetlands, and blue carbon ecosystems support a rich diversity of flora and fauna. Protecting these habitats through sequestration strategies ensures ecological balance.

Livelihood and Economic Opportunities: Sustainable land management, biochar production, and afforestation projects offer employment and income opportunities, particularly in rural and marginalized communities.

Conclusion

The world's cultivable land has significantly declined in quality. Crop input needs are always rising in order to maintain yields, even in high-yielding regions where soil degradation is not thought to be an issue. Given the current food crisis, it is obvious that agriculture needs to be both sustainable and high productive. A key component of the worldwide plan to slow down climate change and create ecosystems that are adaptable to it is carbon sequestration. It symbolizes the meeting point of climate policy, sustainable agriculture, and ecological restoration. Scalable potential to remove CO_2 from the atmosphere are provided by biological, geological, and technological pathways, which also provide crucial co-benefits for biodiversity, soil health, and socioeconomic growth. But effective policies, research-based tactics, funding, and broad engagement are necessary for success. Carbon sequestration will continue to be a key component in guaranteeing environmental, social, and economic resilience as we move to the future.

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Aura of Plant

Sudha Patil, Dixita Prajapati and Dhruvi Badreshiya

Introduction

People and the natural world are closely related. Engaging with nature is crucial for improving people's quality of life and providing them with a number of quantifiable advantages (Dijkstra *et al.*, 2008) including psychological benefits and cognitive performance (Keniger *et al*., 2013). The dictionaries define the word aura as: "Any subtle, invisible emanation or exhalation." The English authorities, as a rule, attribute the origin of the word to a Latin term meaning "air," but the Hindu authorities insist that it had its origin in the Sanskrit root Ar, meaning the spoke of a wheel, the significance being perceived when we remember the fact that the human aura radiates from the body of the individual in a manner similar to the radiation of the spokes of a wheel from the hub there of (Trewavas, 2014). The Sanskrit origin of the term is the one preferred by occultists, although it will be seen that the idea of an aerial emanation, indicated by the Latin root, is not foreign to the real significance of the term. Energy transmission between particles powers everything in the world. Food is essential to our existence since it gives us energy. When viewed through the lens of atomic motion, which is powered by energy, these atoms simply collide before changing into matter, which makes up and builds the enormous earth as well as the cosmos. The energy or essence that a plant exudes is generally referred to as its aura. This energy or essence can be felt in a variety of contexts, such as aesthetics, spirituality, or even holistic health. As mentioned by sattamuni gnanam "Andathil ullathe pindam, Pindathil ullathe Andam, Andamum Pindamum ondre, Aarinthu thaan parkum pothey." In the lines, the realized saint explains that energy is everything that is only present inside the atom and also in the universe. In humans, energy emission around the body is known as aura, which only regulates the mental human behaviour. Aura is subtle, energy emission field that some believe surrounds living beings, particularly humans. While auras are often associated with spiritual and metaphysical beliefs, they are not scientifically recognized phenomena. However, there are various methods people use to measure or interpret auras, often based on subjective or anecdotal experiences rather than rigorous scientific measurement. Aura can be measured by Kirlian Photography, Biofeed-back devices, Subjective observation, Chakra testing, Dowsing tools, Electro encephalography,

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and High-speed photodetectors (Bais *et al*., 2006). It has been observed that engaging with the outdoor natural environment has significant positive physiological and psychological health benefits. This suggests that integrating the natural environment into indoor space can be an effective way to extend engagement with nature and benefit people (task performance, health and stress) (Bringslimark *et al*., 2009).

Why is Aura Generated in Plants?

Plants generate various forms of energy and signals as part of their physiological and metabolic processes.

Biophoton Emission: Plants emit weak light in the form of biophotons, which are ultra-weak light emissions. These are thought to be associated with metabolic processes and can potentially play a role in communication amongst plants.

Electromagnetic Fields: The passage of charged particles within plants creates electromagnetic fields, which can impact their surroundings and possibly other plants or organisms, much like in all living things.

Chemical Signaling: Plants can release volatile organic compounds (VOCs) that serve as chemical signals. When a plant is under threat from herbivores or diseases, it can emit these signals to attract predators or warn neighboring plants.

Root Exudates: Plants also interact with their soil environment through root exudates, which can alter the microbial community in the rhizosphere and potentially influence nearby plants.

Table 1: Comparison between Human and Plant Aura

Plant Aura	Human Aura
Shaped depends on the plant species	Usually oval in shape
Only contains green, brown, and beige	It contains red, orange, yellow, green, blue, indigo and violet.
Energy pattern is more stable, rhythmic energy	It is the complex Pattern reflecting their thoughts, emotions.
It is influenced by environmental stimuli and natural rhythms	It is influenced by consciousness, thoughts and emotions.
It is more connected with natural environment such as soil, water and other plants.	It is influenced by relationship with others

Connections of Plant's Aura with Humans

Plants species especially angiosperms cover 80% of the Earth. In day to day, ecosystem is balanced by the plants only. Plants are not only producing oxygen and also releasing energy in the form of aura that can be easily utilised by the human by connecting with plants. The idea of an interaction between human and plant auras is often linked to concepts in alternative medicine, spirituality, and metaphysics.

Understanding Auras

Human Aura: Many believe that humans possess an aura, a field of energy surrounding the body that reflects emotional, physical, and spiritual states. This aura can be perceived as colors, light, or vibrations by some individuals.

Plant Aura: While plants may not have auras in the same sense as humans, some people believe that plants emit energy fields or vibrations that can interact with those of humans.

Types of Interactions

Emotional Connection: Many individuals report

feeling calm or happier in the presence of plants, suggesting a beneficial interaction between human and plant auras. Studies have also shown that being around greenery can reduce stress and improve mental health.

Energetic Exchange: Some metaphysical beliefs propose that humans can absorb energy from plants, which may contribute to overall well-being and vitality. This idea posits that plants, through photosynthesis and natural processes, produce energy that can positively influence human energy fields.

Healing Properties: Certain plants are thought to have healing or protective properties that extend to their aura, potentially influencing the human aura positively. Herbal medicine, aromatherapy, and ethnobotanical practices support this belief.

Scientific Perspective

While the concept of auras is not widely accepted in mainstream science, there is evidence that plants can influence human health. For example, the presence of plants can improve air quality and enhance emotional well-being. Concepts such as phytotherapy (using plants for healing) have been studied in scientific contexts, although they may not directly relate to the idea of auras.

Practical Applications

Gardening and Horticulture Therapy: Activities like gardening, caring for houseplants, and forest bathing can establish a more profound connection with nature and positively affect mental health.

Mindfulness and Meditation: Some practices involve meditating on the energy exchanged between humans and plants, promoting feelings of connectivity and balance.

Cultural Perspectives

Different cultures and spiritual traditions have varying beliefs about the energy of plants and their interactions with humans. For example, indigenous cultures often view plants as vital partners and have extensive knowledge about their properties and uses.

Characteristics of Plants Aura

Color: Proponents believe that a plant's aura may exhibit different colors, which can indicate its emotional and physical state. For example, vibrant greens might signify health, while dull colors could suggest stress or disease.

Brightness/Dynamic: A bright aura is often seen as a sign of a healthy and thriving plant, while a dim or cloudy aura might indicate that the plant is struggling or unhealthy.

Size: The size and expansiveness of a plant's aura may vary, with larger auras suggesting strong vitality and energy, while smaller auras could imply some form of stress.

Movement/Interconnection: Some traditions hold that the aura can be dynamic, with fluctuations in energy that correlate with external factors such as light, water, and nutrient availability.

Responses to Care: Some practitioners believe that the aura can change in response to care practices, such as watering, pruning, or fertilizing, indicating the plant's reaction to nurturing.

Influence of Environment: Factors such as soil quality, light, temperature, and the presence of other organisms can affect the plant's aura, reflecting the impact of its environment on its vitality.

Plants Emitting Greatest Aura

Although the idea that plants radiate an "aura" has not been proven by science, many holistic and metaphysical traditions identify certain plants with powerful energy and good vibrations. A list of several plants that are commonly cited in these circumstances is provided below:

Basil (*Ocimum basilicum*): Often considered a plant of prosperity and protection, basil is thought to emit a vibrant energy that promotes well-being.

Aloe Vera (*Aloe barbadensis* miller): Frequently referred to as a healing plant, aloe vera is believed to have a strong protective aura and is also associated with health and regeneration.

Palo Santo (*Bursera graveolens*): This sacred wood is used for cleansing and healing in many cultures and is thought to radiate positive energy.

Ficus (*Ficus* sp): This family of plants is often thought to foster a nurturing environment and enhance tranquility, embodying a strong, stabilizing energy.

Cactus (Various species): Some believe that certain cacti can emit a strong protective aura and help deflect negative energy.

Lotus (*Nelumbo nucifera*): A healthy lotus is revered for its power, purity, and rebirth and is frequently seen to radiate a vivid vitality. Despite growing in murky waters, lotuses eventually climb to the top and bloom exquisitely. This trait could manifest as an aura that represents fortitude, tenacity, and the capacity to overcome obstacles.

Conclusion

Plant auras are not grounded in objective research, but rather in metaphysical, cultural, and spiritual ideas. Others frequently have diverse perspectives on the energy of plants, and personal preferences for certain plants can also affect how others perceive their "aura." Through attributes like color, brightness, size, and texture, a plant's aura can provide insight into its emotional state, vitality, and overall health. Although fascinating, these concepts are outside the purview of empirical science, which is concerned with quantifiable and visible facts. The concept might improve the way people who practice holistic medicine connect with plants and cultivate a greater understanding of the importance of taking care of them. However, biological and ecological concepts that describe plants' growth, health, and interactions with their environment are still crucial for a scientific understanding of plants.

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Utilization of Silkworm for Cordyceps Production

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Introduction

Mushrooms have been widely used as important food ingredients all over the world. There are many types of mushrooms with characteristic aroma and texture, which attract great attention. They are considered healthy foods due to their low calorie and various beneficial ingredients such as polysaccharides, phenolics and triterpenoids (Bhambri *et al*., 2022). The word *Cordyceps* originates from the Greek term “kordyle”, which means “club”, and the Latin etymon “ceps”, which means “head” (Olatunji *et al*., 2018). *Cordyceps* species invade insects, arthropods, other fungi, and evades the host immune system by harmonizing the life cycle of its host with the intention of survival and multiplication. A parasitic fungus known as Cordyceps has long been coveted as an exotic traditional Chinese medicine (TCM) with an over whelming list of pharmacological properties. Cordyceps are the most diverse genus of the Clavicipitaceae family in the Order Hypocreales. Over 400 species have been reported (Sung *et al*., 2007) making classification a rather tedious task. Each individual species is specific to a singular host species, insect caterpillars. The caterpillar fungus known as *Cordyceps sinensis* (Berk) Sacc. stands out as the most documented species of Cordyceps with reports from Tibetan doctors dating as far bac k as the late 1400. The natural production of *Cordyceps* undoubtedly sum-moned the interest of first discoverers. The fungal spore s infect and take over the host organism causing its eventual demise. The fungus continues to grow and emerges from the corpse of the host organism. Adding to the mystique is the location in which the relationship between the fungus and the larva of the ghost moth occurs. The caterpillar fungus lives on the Tibetan Plateau including parts of India and wes-tern China, otherwise known as the ‘Roof of the World’. During the 1993 National Games in Beijing, China where three female runners set 5 world records for the 1500, 3000 and 10,000 meter race s. After testing negative for anabolic steroids and other banned substances, it was later revealed by the coach that the runners had taken *C. sinensis* extracts. Traditionally found in the Himalayan regions growing parasitically on cater-pillars, Cordyceps has been revered in Traditional Chinese and Tibetan Medicine for centuries. However, due to its rarity and high market demand, scientists and entrepreneurs have turned to innova-tive cultivation methods and among them, using silkworm pupae as a host substrate has emerged as

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a practical and profitable approach. The different species of *Cordyceps* have beneficial properties such as anti-cancer, anti-proliferative, anti-angiogenic, anti metastasis, apoptosis induction, anti-inflammatory, antioxidant, anti-fibrotic, anti-arteriosclerosis, anti-hypertensive, antithrombotic, antimalarial, antifungal, hypolipidemic, antidiabetic, hypoglycemic, anti-asthmatic, steroidogenesis, spermatogenic, anti-aging, and immunomodulatory effects (Liu Y *et al*., 2015). These properties are concentration-dependent, and in most cases, no adverse effects were reported, although the evaluation of isolated compounds such as cordycepin is preferred.

Why Use Silkworms for *Cordyceps* Cultivation?

Cordyceps is considered a symbol of "Yin and Yang" in traditional Chinese medicine, signifying a healthy balance between plant and animal origins. The two species that are most frequently used and highly prized in traditional Asian medical systems are *Cordyceps militaris* and *Sinensis*. However, *C. sinensis* is incredibly uncommon in nature, and growing it presents several difficulties. Because of its similar chemical components and pharmacological characteristics, *C. militaris*, an orange-colored entomopathogenic fungus has become well-known as a good alternative. Due to increasing demand, *Cordyceps militaris* has been extensively overharvested in the wild, resulting in its scarcity. This has necessitated the development of alternative cultivation methods using synthetic substrates. Silkworms, which are rich in carbohydrates and moisture while being low in fat, have emerged as a promising biological substrate for *C. militaris* cultivation. They support the formation of fruiting bodies, from which valuable bioactive compounds such as cordycepin and adenosine can be efficiently extracted.

Life Cycle: The caterpillar fungus, commonly known as *Cordyceps*, exhibits a complex life cycle that is influenced by multiple ecological factors, including the availability of suitable insect hosts, soil composition, and precipitation patterns. The fungus infects subterranean caterpillars, typically residing about 15 cm (5.9 inches) below the soil surface. These larvae, which feed on plant roots, become susceptible to fungal invasion particularly after molting. Once infected, the larvae tend to position themselves vertically in the soil with their heads facing upward. By early spring, a stalk-like fruiting body-dark brown to black in colour-emerges from the caterpillar's head and protrudes above the soil surface, especially in alpine meadow habitats. In late summer, the mature stroma releases spores, thereby completing the fungal reproductive cycle. After entering the larval host, the *Cordyceps* fungus spreads throughout the body, eventually causing the host to perish. The development of fungal sclerotia-dense, multihyphal structures that can remain quiescent in adverse conditions causes the infected larvae to become rigid. The fungus breaks through the host's cuticle after overwintering and develops a fruiting body, usually a perithecial stroma, that protrudes from the larval head. This fruiting body

Table 1: Morphological features and Habitat of *Cordyceps*

Features	*C. sinensis*	*C. militaris*
Colour	Dark brown to black	Bright orange or reddish
Host	High-altitude caterpillars (Thitarodes)	Low-altitude moth larvae/pupae
Fruiting body shape	Slender, clavate	Club-shaped, often thicker
Spore structure	Filiform ascospores in perithecia	Asci with filiform ascospores
Size	5–15 cm (fruiting body)	1–5 cm (fruiting body)
Cultivation	Difficult (natural only)	Easily cultivable on artificial media
Region	Himalayas (India, Tibet, Nepal)	Asia, Europe, N. America
Host	Thitarodes caterpillar	Lepidopteran larvae/pupae

remains connected to the sclerotized cadaver below ground and grows upward through the soil, completing the reproductive cycle through sexual sporulation. Climate change is believed to significantly impact this delicate mountain ecosystem, potentially affecting both the fungal development and host availability. In nature, *Cordyceps sinensis* parasitizes ghost moth caterpillars in the wild, but such harvesting is unsustainable and ecologically damaging. *Cordyceps militaris*, which can be cultivated artificially, is a more sustainable and equally potent alternative. Silkworm pupae (*Bombyx mori*), a byproduct of the silk reeling industry, offer a cost-effective, protein-rich medium for *Cordyceps* growth. Silkworms are widely available in sericulture regions, especially in India, China, and Southeast Asia.

Method of Cultivation

Preparation of Silkworm Pupae

- ✓ Use fresh or freeze-dried pupae from healthy silkworms after cocoon reeling.
- ✓ Pupae are sterilized (autoclaved at 121°C for 20 minutes) to eliminate contaminants.
- ✓ Optionally, mix with rice or wheat bran to improve aeration.

Inoculation with Cordyceps Culture

- ✓ Use pure *Cordyceps militaris* mycelium, which can be obtained from culture banks or previous generations.
- ✓ Inoculate sterile pupae with liquid or solid mycelium under aseptic conditions in glass jars or plastic containers.

Incubation Conditions

- ✓ Incubate at 20-24°C with 70-80% humidity.
- ✓ Keep in dark conditions during the early phase for rapid colonization.
- ✓ After mycelium fully covers the pupae (10-15 days), shift to lighted conditions (12:12 light/ dark cycle) to induce fruiting.

Fruiting and Harvesting

- ✓ Fruiting bodies appear in 2-3 weeks.
- ✓ Harvest when they are 4-5 cm long and fully developed, usually after 45-60 days.
- ✓ Dry under low heat (below 45°C) to retain bioactive compounds.

Economics and Market Potential

The market price of cultivated *Cordyceps* ranges from ₹12,000 to ₹15,000 mg g^{-1} depending on quality. The return on investment is high, especially for small-scale sericulture farmers or entrepreneurs using silkworm pupae, as they utilize what is otherwise considered a waste product. Additionally, the spent substrate can be composted or used as organic fertilizer, promoting a zero-waste circular model.

Conclusion

The cultivation of Cordyceps using silkworm pupae represents a fusion of traditional sericulture and modern biotechnology. It not only adds economic value to sericulture waste but also creates new employment avenues in rural and peri-urban areas. With rising global demand for natural and functional health products, this innovation could revolutionize integrated bio-farming and make India a global leader in medicinal mushroom production.

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Bacillus amyloliquefaciens: Potential Biocontrol Agent against Plant Diseases

Sumana K., Rathinakumar G. and Apurba Das

Introduction

Increased agricultural output is necessary given the existing global population, but inappropriate management of agricultural land-such as the overuse of artificial fertilizers and pesticides is impeding this output (Kazerooni *et al*., 2021). One of the main factors limiting plant growth and productivity in agricultural soils is nitrogen and mineral deficiencies. For example, plants primarily require inorganic nitrogen even if the topsoil contains up to 95% of its nitrogen in organic form. As a result, plants can easily access only a very small amount of nitrogen in the soil. To meet the growing demand for food and address a reduction in soil nutrients, several chemical fertilizers have been utilized in recent decades. The price of producing crops has also gone up due to the elevated rate of artificial or synthetic fertilizers, which has reduced farmers' profitability. It is challenging for everyone to enhance the growth of plants and legitimately escalate the yield of food in order to additionally meet the requirements of the emerging global population (Alwang *et al*., 2019). Abiotic stressors including bacterial and fungal infections are detrimental to plant development and yields in addition to nutrient shortages. For example, anthracnose disease, which is brought on by the fungus *Colletotrichum truncatum* and affects 50% loss of total yield globally, can cause severe infection in chili plants which is one of the utmost important harvests in the world. The use of microbes as representatives of biofertilisers has been commended and regarded as a substitute green method in order to preserve agricultural yield and well-being while avoiding the use of artificial fertilizers. A gram-positive bacterium called *Bacillus amyloliquefaciens* may colonize the rhizosphere of plants and thrive in stressful environments. According to the study conducted by Qiao *et al*. (2014), it has been investigated as harmless and environmental friendly to promote plant development. *Bacillus amyloliquefaciens*, one of the plant growth-promoting rhizobacteria, is utilized to increase plant tolerance to biotic and abiotic challenges as well as to explore biofertilisers and biocontrol in agriculture. *Bacillus amyloliquefaciens* has been demonstrated to promote plant development in in vitro as well as in vivo conditions, and also in field investigations by produ-

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cing various hormones, volatile organic compounds, and siderophores, increasing the availability of nutrients in the soil, and preventing the soil pathogens (Sheteiwy *et al*., 2021).

Taxonomy and Characteristics of *B. amyloliquefaciens*

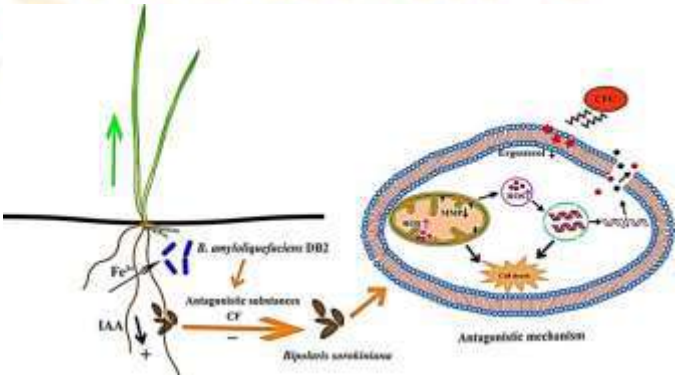
B. amyloliquefaciens belongs to the genus Bacillus, within the phylum Firmicutes. It is closely related to *Bacillus subtilis*, and both share many physiological traits. *B. amyloliquefaciens* is a Gram-positive, aerobic, spore-forming, rod-shaped bacterium. Its ability to form resilient endospores enables it to survive extreme conditions, making it ideal for field applications. Notably, this bacterium is commonly found in soil and associated with the rhizosphere of various plants. Its genome contains clusters responsible for producing secondary metabolites that function as antimicrobials and signaling molecules.

Mechanisms of Biocontrol Activity

Production of Antimicrobial & Volatile Organic Compounds: The bacterium produces an array of secondary metabolites, including lipopeptides such as surfactin, iturin, and fengycin, which disrupt the membranes of fungal pathogens. It also produces polyketides and dipeptides like bacillaene, difficidin, and bacilysin with strong antibacterial properties. Produces lipopeptides (e.g., iturin, fengycin, surfactin) that kill or inhibit pathogens. In both molecular studies and field control experiments, *B. amyloliquefaciens* has been shown to produce hormones and volatile organic compounds that can promote plant growth. Previous research has shown that *B. amyloliquefaciens* has genes involved in the production of IAA. IAA has the ability to regulate practically every process involved in plant growth, including cell division, elongation, fruit formation, and stimulation of the growth of root hairs. VOCs are signalling molecules that have positive impacts on plant growth, including modulating endogenous hormone levels in host plants and encouraging lateral root formation that may further improve plant nutrient intake (Ji *et al*., 2021).

Example 1: Disease: Fusarium wilt of tomato (*Fusarium oxysporum*) Mechanism: Iturin and fengycin disrupt fungal membranes.

Example 2: Disease: Anthracnose in chili (*Colletotrichum capsici*) Mechanism: Lipopeptides suppress spore germination and fungal growth.



Triggering the Induced Systemic Resistance of Plant: Numerous bioactive secondary metabolites produced from BA have been proven in in vitro studies to have the ability to control soil pathogens. Surfactins were the only antifungal lipopeptides in the plant with a rather low concentration. Furthermore, plant roots that had been colonised by BA did not contain any polyketides or other bioactive

substances against bacteria. Surfactins and other secondary metabolites may thus cause systemic resistance to inhibit the pathogens, according to researchers (Shao *et al*., 2015). Systemic resistance refers to the improvement of defensive capability as a result of local stimulation of nonpathogenic bacteria, as opposed to systemic acquired resistance, in which the response is driven by pathogenic microorganisms associated with the aerial sections of the plant.

Enzymatic Lysis of Pathogen Cell Walls: It produces lytic enzymes such as chitinases, cellulases, proteases, and glucanases that degrade the structural components of fungal pathogens. Produces enzymes like chitinase, glucanase, and protease that degrade fungal cell walls.

Role of *B. amyloliquefaciens* in Disease Management

Zhao *et al*. (2013) investigated the biocontrol potential of *Bacillus amyloliquefaciens* Q-426 against various plant pathogens. Genomic analysis identified the presence of the fen and bmy gene clusters, which are associated with the synthesis of antifungal compounds. Lipopeptides, including bacillomycin D, fengycin A, and fengycin B, were extracted from the bacterial culture broth and characterized using ESI-mass spectrometry. Fengycin A exhibited strong antifungal activity, with a minimum inhibitory concentration of 31.25 µg ml^{-1} against *Fusarium oxysporum* f. sp. *spinaciae* W.C. Snyder and H.N. Hansen O-27.

Liu *et al*. (2019) suggested that the inhibition of *Phytophthora sojae* by the bacteria may primarily result from interference with ribosomal activity. In a pot experiment, both *Bacillus amyloliquefaciens* and *Bacillus subtilis* were shown to enhance soybean resistance to *P. sojae*, achieving control efficiencies of 70.7% and 65.5%, respectively.

Using a dual culture experiment, Ji *et al*. (2021) discovered that the *B. amyloliquefaciens* strain CNU114001 had broad-spectrum antifungal activity against 12 distinct phytopathogenic fungi. At a concentration of 200 parts per million, a semi-purified chemical from this strain efficiently inhibited the mycelial growth of multiple fungal diseases, including *Alternaria panax, Botrytis cinerea, Colletotrichum orbiculare, Penicillium digitatum, Pyricularia grisea*, and *Sclerotinia sclerotiorum.* Furthermore, the culture filtrate prevented Botrytis cinerea spores from elongating their germ tubes. In laboratory settings, the crude antifungal extract also showed antagonistic effects against cucumber sclerotinia rot. In greenhouse studies, it was effective in suppressing tomato gray mold and powdery mildew on cucumber and pumpkin.

Conclusion

To encourage plant growth and food production without putting the environment or human health at needless risk, eco-friendly alternatives are essential to lowering the overuse of pesticides and chemicals. derived fertilizers. Accordingly, *B. amyloliquefaciens* strains can support plant growth in a number of ways, such as

increasing nitrogen supply, releasing potassium from insoluble forms, solubilizing inorganic and organic phosphate, and producing siderophores to chelate iron. Ions will also make more soil nutrients available.

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Bio-Input in in Soil Fertility

Sumana K., Harshvardhan Bhagwan Gokhale and Premsagar Nishad

Introduction

Agroecological transition is a process of transforming agricultural systems to enhance their sustainability, resilience, and productivity, while minimizing their negative impacts on the environment and society. Agricultural systems depended on internal resources, recycling of organic matter, built-in biological control mechanisms, and rainfall patterns to provide essential ecosystem services, such as nutrient cycling, pest control, soil health, and water regulation. It is anticipated that technological advancements in the bioeconomy will open up new markets for investments that address issues like climate change, food security, and resource depletion (Wydra *et al*., 2020). The increasing demand for sustainable farming around the world creates opportunities for prospects for investments in agro-industrial facilities that generate bio-inputs, such bio-fertilizers and bio-pesticides, from microorganisms like fungi and bacteria since they are environmentally friendly and lower farming expenses (Prasad *et al*., 2022). Agricultural bio-inputs are considered a crucial area for global investment, and poor nations can take advantage of this market by investing in open-source biotechnology and biotech partnerships to join the bioeconomy (Lee, 2016). Agribusiness growing sectors that deploy locally available technology provide areas of opportunities for investments that build agro-industrial capabilities in developing countries. Developments in agricultural bio-inputs range from average technology used for isolating and reintroducing specific microorganisms to promote beneficial interactions with plants up to high-tech phytomicrobiome engineering based on gene transfer. Bio input technologies have gone through continued technological developments made by private investments that often collaborate with public innovation centers. Agricultural bio-inputs gained initial market momentum by addressing demands from organic and agroecological farmers and its importance grew recently in conventional agriculture as an alternative for dealing with pests not controlled by chemical pesticides and also as an alternative for fertilizers whose prices grew given to the COVID-19 pandemic related trade disturbances and the war in Ukraine. Soil fertility, a cornerstone of productive agriculture, is determined by the availability of essential nutrients, soil organic matter content, microbial diversity and physicochemical characteris-

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tics. Conventional agriculture heavily relies on chemical fertilizers, which though effective in the short term, have led to long-term ecological imbalances, such as nutrient leaching, soil acidification, and biodiversity loss (Lal, 2020). In contrast, bio-inputs restore the natural fertility of soils by harnessing biological processes and promoting soil-microbe-plant interactions.

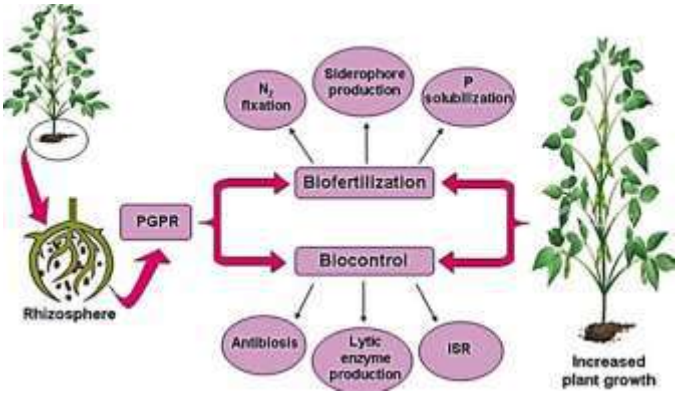
Classification of Bio-Inputs

Bio fertilizers: Because they fix air di-nitrogen and mobilize fixed macro and micronutrients in the soil into forms that plants can use, bio fertilizers which are crucial parts of organic farming help preserve long-term soil fertility and sustainability. Applications of biofertilizers to soils, seeds, or plant surfaces include "substances which contain living microorganisms which colonize the rhizosphere or the interior of the plants and promote growth by increasing the supply or availability of primary nutrients to the target crops." By improving the host plant's accessibility and uptake of mineral nutrients, they colonize the rhizosphere, which surrounds the interior of the plant, and promote growth. These preparations contain microorganism cells that can act as organic matter decomposers, P-solubilizers, S-oxidizers, or N fixers. Through their regular metabolic processes, these "eco-friendly" organic agro-inputs seek to transform inaccessible vital elements into forms that are readily available.

Nitrogen fixers: *e.g., Rhizobium, Azospirillum, Azotobacter*

Phosphate solubilizers: *e.g., Bacillus megaterium, Pseudomonas striata*.

Potassium mobilizers: *e.g., Frateuria aurantia.*



Biostimulants: A variety of chemicals and microbes that promote plant growth are referred to as plant biostimulants or agricultural biostimulants. Due in part to the wide range of inputs that can be classified as biostimulants, the definition and idea of plant biostimulants are continually developing. Examining two projects from alliances of the biostimulant businesses, one in North America and one in Europe, demonstrates the scope of the idea of biostimulants. The EBIC provided the following definition of plant biostimulants in Europe. When applied to plants or the rhizosphere, plant biostimulants-which include substances and/or microorganisms stimulate natural processes that improve crop quality, nutrient uptake, nutrient efficiency, and tolerance to abiotic stress.

Microbial Consortia: The use of microbial inoculants in agriculture has great ly increased during the past two decades (Hayat *et al*. 2010) as the public and private sector agricultural re search and development communities work for solu tions to problems associated with modern agriculture. Microbial inoculants are typically classified as biocon trol agents (also called biopesticides) or

biofertilizers. Microbial inoculants mainly include free-living bacteria, fungi and arbuscular mycorrhizal fungi (AMF). Different plant species or cultivars can produce different types of root exudates, which support the activity of the inoculated microorganisms and also serve as substrates for the formation of biologically active sub stances by the microorganisms.

Organic Amendments: Building soil organic matter is a central aim and outcome of organic soil health practices. Plant residues, animal manures, compost, and other carbon-based soil amendments fuel soil microbes and fauna while enhancing moisture and nutrient retention and binding properties. In the face of rising inorganic fertilizer costs and environmental impacts, optimizing and sustaining soil organic matter offers farmers natural fertility derived from organic nutrient cycling instead of costly external inputs with substantial embedded energy costs. Increasing soil carbon content not only enhances productivity but also mitigates climate change through carbon sequestration and reduced nitrous oxide emissions. Compost and animal manures have long been used as organic amendments, providing a slow release source of nutrients along with organic matter and microbial populations. More concentrated organic amendments like bone, blood, and feather meal can strategically supply nutrients like nitrogen and phosphorus. Allowing lands to rest in cover crops or pasture through crop rotations supplies renewable organic matter.

Mechanism of Action of Bio-Inputs

Nutrient Acquisition and Cycling: Symbiotic (Rhizobium-legume) and free-living (*Azotobacter, Azospirillum*) microbes convert atmospheric N_2 to ammonia. Production of organic acids by microbes such as *Aspergillus niger* and *Pseudomonas spp*. helps release bound phosphates. Certain bacteria release chelators or enzymes that help in mineral weathering and micronutrient solubilization.

Enhancement of Soil Organic Matter: Organic amendments improve soil structure, water-holding capacity, and cation exchange capacity (CEC), thereby enhancing nutrient retention and availability (Lehmann and Kleber, 2015).

Promotion of Beneficial Microbial Activity: Bio-inputs increase microbial biomass, enzyme activity (e.g., dehydrogenase, urease), and biodiversity, essential for nutrient cycling and plant health.

Plant Growth Promotion: Certain rhizobacteria produce phytohormones such as IAA, gibberellins, or ACC deaminase, promoting root growth and nutrient uptake.

Benefits of Bio-Inputs

- ✓ Improved soil texture and porosity.
- ✓ Enhanced aggregation and reduced compaction.
- ✓ Increased soil pH in acidic soils through organic matter buffering.
- ✓ Increased water retention.
- ✓ Improved C:N ratio and organic carbon content.
- ✓ Enriched microbial diversity and biomass.
- ✓ Elevated enzymatic activities (phosphatases, nitrogenases).
- ✓ Reduced soil-borne pathogen loads due to comp-

etitive exclusion and antagonism

Conclusion

By increasing microbial activity, boosting nutrient availability, and preserving ecological balance, bio-inputs are essential for reestablishing soil fertility. Even though their advantages are widely known, broader implementation need for coordinated research, quality control, legislative support, and farmer education. These sustainable technologies must be incorporated into agriculture in the future to combat soil erosion and guarantee long-term food security.

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Entomophagy: Future of Food Security

H. Vanlalhmuliana, C. Rachael, Lalthasangi and Ajay Baldaniya

Introduction

The relationship between humans and animals has varied throughout history and across different cultures. For centuries, humans have hunted animals for food or fur, besides using them for transportation or labor. In addition, animals have been caged for people's pleasure or tamed to be exploited in various ways. In particular, the domestication of animals such as cows, sheep, and horses enabled humans to establish settled agricultural societies, thus playing a significant role in human history by providing benefits in terms of food, transportation, farming, and companionship (Lesnik, 2018). Historically, people have frequently associated animals including insects with spiritual meaning and revered them as sacred or symbolic entities. They still serve as reminders of the natural environment and our relationship to it, even in modern times and the life-and-death cycles. Cows are revered in Hinduism and are not to be injured. To be more precise, Brahmins never handle or consume any meat, fish, or eggs, although members of the other three castes - Kshatriya, Vaisya and Shudra occasionally consume these foods as well as chicken, goat, or mutton, but never on holy days (Meyer-Rochow, 2009). Animals and humans have historically had a complicated and sometimes contradictory connection. Although animals have always been necessary for human survival, overhunting, pollution, and habitat degradation have also negatively impacted animals. However, the necessity of striking a balance between meeting human needs and protecting the environment is becoming increasingly apparent these days. There are numerous things we can do to maintain the equilibrium that is essential to the planet's long-term sustainability. Entomophagy is the term used to describe the process of eating insects as food. Although 'microlivestock/mini-livestock' are not equivalent words to entomophagy, they are sometimes used to categorize the insects that can be eaten by human beings. Currently, many ethnic groups in Asia, Africa, Mexico, and South America rely on edible insects as a natural food supply. Entomophagy can be sustainable and benefits rural communities in terms of economy, nutrition, and ecology. However, due to changes in social structures, demography, and the growing use of

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modern foods, entomophagy is becoming less common in some areas. Different edible bug species are preferred depending on factors like flavor, nutritional value, ethnic customs, local laws, family history, and ease of availability.

Why Entomophagy?

- ✓ When their numbers are high, insects can be quickly and easily gathered in large quantities from forests and water sources.
- ✓ 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).
- ✓ In low-income areas, only insects are available in the period of food shortage, particularly at the beginning of the rainy season when livestock is lean, new crops have just been sown and the stocks of stored produce from the previous crop season become limited.
- ✓ Insects are generally combined with, or frequently eaten as a supplement to, diets that primarily consist of grains including rice, beans, sorghum, maize, cassava, and millet. They are also used as an ingredient to make other foods.
- ✓ In addition to local markets, the food industry in developed nations have pioneered the export of insects in the form of beetle juice, canned silkworm pupae, hesperided butterfly caterpillars and immature ant stages.
- ✓ Tribes have utilized entomophagy as a medical treatment on a daily basis for ages, and certain nations still employ this method.
- ✓ Comparing insects to conventional livestock, the former produces a lot less greenhouse gases (GHG, especially methane and nitrous oxide) per kilogram of meat (Oonicx *et al*., 2010). Mealworms emit around 100 times as much greenhouse gas as pigs.

Nutritive value of insects

Apart from the reasons mentioned above, insects have been well recognized worldwide as nutritious food since insects provide proteins (amino acids including methionine, cysteine, lysine, and threonine), carbohydrates, fats, some minerals and vitamins, and have energy value (Xiaoming *et al*., 2010). Exploration on the nutritional composition of edible insects have been done according to internationally accepted guidelines. Due to their wide variety of species, edible insects have a wide range of nutritional properties. Even within the same species of insect, nutritional values can vary depending on the stage of the insect (egg, larvae, pupa, and adult for holometabolous insects, and egg, nymph, and adults for hemimetabolous insects). Diverse analytical techniques, the heterogeneity between insects from various environments, and various rearing and storage conditions can also contribute to this variation in nutrient composition.

The international network of food data systems (FAO INFOODS) has recently published a database on food composition and in version 4.0 a

Table 1: Commonly explored major edible insect species documented from India

Method of processing	Insect species	Order: Family	Insect life stage(s)	State
Baked	*Oecophylla smaragdina*	Hymenoptera: Formicidae	Egg, adult	Assam, Karnataka
	Rhynchophorus phoenicis	Coleoptera: Curculionidae	Larva	Assam
	Rhynchophorus ferrugineus	Coleoptera: Curculionidae	Larva	Assam
Cooked	*Pentatomid* sp.	Hemiptera: Pentatomidae	Adult	Arunachal Pradesh
	Locusta sp.	Orthoptera: Acrididae	Adult	Arunachal Pradesh
Dry/deep fried	*Dihammu scervinus*	Coleoptera: Cerambycidae	Larva	Assam
	Batocera rufomaculata	Coleoptera: Cerambycidae	Larva	Assam
	Meligethes aeneus	Coleoptera: Nitidulidae	Larva	Assam
	Okanagan sp.	Diptera: Asilidae	Larva	Assam
Roasted	*Gryllus campestris*	Orthoptera: Gryllidae	Nymph, Adult	Assam
	Schizodactylus monstrosus	Orthoptera: Gryllidae	Nymph, Adult	Assam
	Vespa tropica	Hymenoptera: Vespidae	Larve	Arunachal Pradesh
	Polistes sp.	Hymenoptera: Vespidae	Larva	Arunachal Pradesh

total of 471 edible insects, with different methods of preparation. Eggs, larvae/nymphs, pupae, and adults of insects all have been consumed in India, probably due to the significant variations in nutrient content that occur over the course of insect life. A high energy value is obtained from eating termites, grasshoppers, caterpillars, and crickets. Content of protein is significantly higher than or equal to animal foods such as, chicken, pork, eggs, beef or lamb. When five insects were compared for nutritive value, high protein content was found in dragon fly, *Crocothermis servilla* larva (70.48%), short horned grasshopper, *Oxyahyla hyla* adult (64.67%), surface grasshopper, *Oedaleus abruptus* adult (60.00%) and eri silkworm, Samiari cini pupa (71.9%). Maximum amino acid amounts of 100 g/100 g dry weight of silkworm pupae have been reported (Yhoung-aree, 2010). The bamboo caterpillar comes in second with 77.5 g and the house cricket comes in third with 68.7 g. Caterpillars, grubs of palm weevils (*Rhyncho-phorus* spp. (Coleoptera: Curculionidae)) and termites are rich in fat. The amount of calories found in insects can reach up to 776.9 kcal/100 g, which is frequently more than the amount found in soybeans, maize, and cattle (Ramos-Elorduy, 2005).

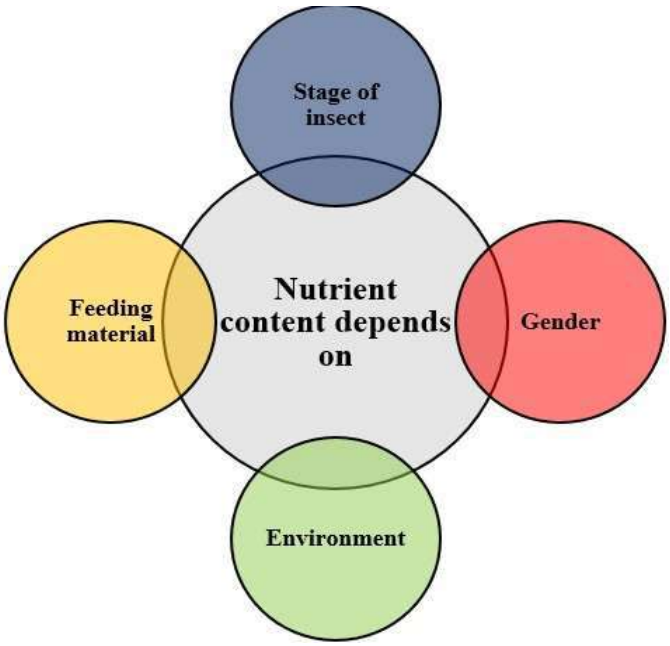
A bread containing grubs of the African palm weevil provides the major and minor nutrients essential for body growth. Eating silkworm caterpillars can meet daily needs for thiamin, copper, zinc, iron, and riboflavin. Eating those insects that contain riboflavin can also help supplement any riboflavin shortage. Insect protein synthesis uses less resources and is ecologically sustainable than that of animal protein. Maximum contents of calcium of 61.3, 72.4 and 76 g/100 g dry weight have been recorded, respectively, in dung beetle grubs (*Oryctes* sp.), palm weevil grubs and adult house crickets. Honeybee eggs, larvae, and pupae are rich in vitamins A, B_2, and C.

Future perspective: Further research is needed to ascertain whether the production of a kilogram of insect protein is also more environmentally friendly than conventional animal protein when the entire production chain is taken into account. Thus, in order to preserve this priceless natural resource and the indigenous knowledge for future generations, it is

necessary to evaluate insect biodiversity and the role that ethno-entomophagy plays, particularly in India. Additionally, there is opportunity to work toward increasing their commercial worth as food and feed for livestock, particularly chickens, and as readily available resources in a sustainable way.

Insects protein as the strength in the food industry

Compared to plant and seed proteins, insect proteins are a more dependable and sustainable supply due to their techno-functional qualities. Proteins' ability to hold water and lipids and thicken food is thought to be a useful characteristic in the manufacture of meat and baked items, as well as in modifying the sensory qualities of beverages and various satiating foods. Insect protein is utilized in salad dressings, sweets, and drinkable dairy products because of its excellent emulsification and moderate foaming capabilities. On the other hand, cheese and tofu have similar gelation and structural properties. The characteristics of these products differ with species, stages, and products. *Gryllodes sigillatus* showed the best solubility along with a wide range of pH, so it is essential in protein flour preparation. *T molitor*, *G. sigillatus* and *Schistocerca gregaria* has better functional characteristics other than any insect's species (Zielinska *et al.*, 2018). Hence, all these uses prove that edible insects could be a better source of protein constituent in food systems.



Conclusion

With increasing awareness of nutritional security issues, it is important that consumption of animal products that are often prone to human diseases is reduced and entomophagy is popularized in India. Eventually, more research is needed to understand prevailing entomophagy in the North East region where indigenous communities enjoy nutritious food with insects as sustainable ingredient in main dish or as supplement. Constraints such as, con tent of anti-nutrients, and contamination of chemicals and biochemical compounds and other

risks to human health (allergic reactions, disease infection, side effects) being minimum, consumption of silkworm larvae and pupae, water bugs, grasshoppers, field crickets, termites and dragon fly larvae would prove beneficial as a local source of protein, minerals and vitamins. 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.

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Importance of Training and Pruning in Horticulture Crops

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Abstract

Training and pruning shape plant architecture, balance vegetative and reproductive growth, and sustain yield and quality in horticultural crops. These practices control canopy size, improve light distribution, and reduce disease pressure. They also enable efficient harvest, fertigation, and pest management. The physiological responses involve source-sink allocation, hormonal gradients, and renewal of fruitful wood. Modern high-density systems depend on rigorous training and size control to remain profitable. This article synthesises principles, methods, and crop-specific systems, with case studies from orchards, vineyards, berries, and greenhouse vegetables. It links canopy design to light interception, microclimate, and fruit quality. It reviews timing, tools, labour economics, and risk management. It outlines research needs for mechanisation, sensing, and climate resilience.

Introduction

Training and pruning are core practices in horticulture. Growers use them to build a stable framework, control vigour, and renew fruiting wood. The aim is simple. Capture light efficiently. Convert carbohydrates into marketable yield. Maintain quality across years. The need is universal across crop groups. Tree fruits, grapevines, berries, and greenhouse vegetables all respond to canopy management. The methods differ by species, growth habit, and fruiting biology, yet the goals converge. Establish the structure early. Maintain balance annually. Adjust for site, scion, and rootstock. Markets and costs raise the stakes. High-density orchards and protected cultivation increase capital intensity. Returns depend on rapid precocity, consistent packout, and low unit labour. Training and pruning enable these outcomes when done with discipline.

Physiological basis: Apical dominance and hormo-

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nal gradients guide canopy development. Terminal buds produce auxin that suppresses lateral growth. Pruning reduces apical dominance, redistributes hormones, and stimulates axillary buds. Cytokinins from roots promote lateral shoot growth. The net effect depends on pruning severity, timing, and vigour status. Source-sink dynamics link canopy size to fruit load. Leaves export assimilates to developing fruits and storage tissues. Excess vegetative growth dilutes light within the canopy and competes with fruit. Insufficient leaf area reduces assimilate supply and weakens renewal. Training and pruning target an optimal leaf area to fruit ratio. Light drives photosynthesis and fruit quality. Sunlit leaves operate at higher photosynthetic rates than shaded leaves. Light also affects colour, phenolics, and dry matter. A well-trained canopy improves light distribution and raises the fraction of productive wood. Ventilation lowers humidity and reduces disease risk. Bud biology is crop-specific. Apples initiate flower buds in the current summer for next year's fruiting. Grapevines carry compound buds that form shoots with inflorescences the following spring. Tomatoes in greenhouse systems produce sympodial inflorescences on trained leaders. These patterns define what wood is fruitful and what must be renewed.

Principles and timing: Train young plants early. Establish a central axis, multiple leaders, or a cordon based on the system. Select strong, well-positioned shoots. Remove weak or competing shoots before they lignify. Early decisions save years of correction later. Prune annually to maintain balance. Use minimal cuts on young high-density systems to reach canopy fill quickly. Shift to renewal pruning once bearing begins. Avoid alternating between heavy and light cuts. Aim for steady renewal of moderately vigorous wood. Time cuts for defined goals. Dormant pruning removes stored reserves and often invigorates the plant. It is helpful to renew the structure and remove crowded wood. Summer pruning and shoot positioning control vigour and improve light exposure. They can reduce pruning needs in winter and lower disease risk by opening the canopy during the season. Choose cuts by function. Heading cuts shorten a shoot and stimulate nearby buds. Thinning cuts remove a shoot or branch at its point of origin and reduce crowding. Bending and tying convert vertical vigour into fruitful horizontal positions. Notching and scoring can break apical dominance at specific nodes when needed.

Systems across crop groups

Pome fruits: Modern apple systems favour slender axes with short fruiting units. Tall Spindle uses a single axis, short renewal spurs, and narrow walls. It demands early leader dominance, strict branch angle management, and continuous spur renewal. Pears follow similar logic with more attention to vigour control and branch bending.

Stone fruits: Peach and nectarine bear on one-year-old shoots. Systems focus on renewing fruiting shoots each year. Open centre or vase systems spread scaffold branches and allow intense light penetration. In high-density peaches, perpendicular V systems

create fruiting walls for mechanisation.

Citrus: Citrus needs less pruning but benefits from canopy thinning and skirt lifting. Remove deadwood and crossing branches. Maintain canopy skirts above the ground to improve airflow and reduce Phytophthora risk. Moderate hedging and topping stabilise height for harvest and sprayer access.

Grapevines: Grapevines are trained to cordons or canes with vertical shoot positioning. Spur pruning on bilateral cordons is familiar with low to moderate vigour. Cane pruning suits cultivars with basal bud infertility or in cool regions. Shoot thinning and leaf removal fine-tune cluster exposure and disease control.

Small fruits: Blueberries need annual removal of the oldest canes and promotion of strong new canes. Raspberries require floricane removal after harvest and selection of primocanes. Kiwifruit relies on cordons with renewal spurs and regular replacement of fruiting laterals.

Greenhouse vegetables: Indeterminate tomatoes and cucumbers are trained to single or double leaders on high wire systems. Leaf removal keeps the lower canopy clean and reduces humidity around fruit. Lateral removal manages sink strength and maintains harvest rhythm. Deleafing follows strict rules to preserve photosynthetic capacity while controlling microclimate.

Canopy architecture, light and microclimate: Light interception has two parts. Capture and distribution. Total capture depends on leaf area index and canopy surface. Distribution depends on the arrangement of shoots, spur density, and inclination. Training defines both. Narrow fruiting walls increase the ratio of exterior, well-lit leaf area. They also simplify airflow and spray coverage. Wide canopies increase self-shading and promote gradients in fruit quality. Empirical targets help. For apples, maintain a spur leaf area that supports the crop load without excessive shading. For grapes, limit shoots per meter of row and maintain a defined leaf layer number. For tomatoes, maintain a stable number of active leaves above the most recent cluster. Microclimate follows structure. Open canopies dry faster after rain or irrigation. They show lower leaf wetness duration and reduced disease risk. Leaf removal around clusters reduces Botrytis in grapes. Skirt lifting in citrus reduces ground humidity near fruit. Summer tipping in apples improves colour development by exposing fruit surfaces to light during maturation.

Yield and fruit quality: Training and pruning do not create yield. They shape where yield forms and how consistent it remains. The outcome depends on the interaction with rootstock, nutrition, irrigation, and crop load management. Fruit size responds to leaf area per fruit. Over-cropping reduces the size and return bloom. Undercropping increases vigour and reduces quality. Training systems that stabilise crop load improve year-to-year consistency. Summer pruning can increase colour in red apples by exposing the fruit in late summer. In grapes, balanced pruning aligns bud number with vine vigour. It reduces cluster compactness and improves ripening uniformity.

In tomatoes, single leader systems produce uniform trusses and predictable harvest flow. Quality attributes depend on exposure and temperature. Moderate sunlight improves antho-cyanins and carotenoids in fruits. Excess exposure can cause sunburn, bleaching, or loss of firmness. The correct level is system-specific. Use light measurements or simple index cards to monitor exposure around fruiting zones. Adjust leaf removal and shoot positioning to stay within target ranges.

Vigour control and rootstock interactions: Root-stock choice sets vigour potential. Training and pruning express or restrain that potential. Dwarfing rootstocks in apples enable high density and early bearing. They require strict leader control and branch renewal to avoid spur crowding. Semi-vigorous rootstocks need more structural pruning and limb bending to induce cropping. Pruning severity interacts with vigour. Heavy dormant pruning often stimulates strong regrowth. This can worsen shading and delay fruiting. Light but consistent renewal cuts maintain moderate vigour and stable cropping. Summer pruning reduces vigour by redirecting resources during the growing season. Combine summer interventions with crop load targets to prevent overstimulation of vegetative regrowth.

High-density and planar canopies: High-density orchards, hedgerow berries, and vertical vineyards share design principles. Keep the canopy thin. Align rows to manage solar angles and wind. Use repeatable units that support mechanisation and sensing. Planar canopies increase the feasibility of mechanized pruning, hedging, and harvest aids. They simplify machine vision for robotic operations. They also improve spray deposition and reduce drift. The shift from large, free-growing trees to narrow fruiting walls has transformed orchard economics. It front-loads yield into the early years and stabilises labour inputs.

Protected cultivation of vegetables: In green-houses, training and pruning are production tools that drive weekly yield. Tomatoes are commonly trained to a single leader. Workers remove axillary shoots to maintain the leader and set a stable number of leaves. Deleafing of older leaves below harvested clusters reduces disease risk and improves airflow. High wire systems allow clipping and leaning to manage plant height and maintain headspace near the roof for optimal light. Cucumbers use similar logic with modifications by cultivar. Gynoecious cucumbers in high wire systems maintain a single leader and set fruit at frequent nodes. Shoot removal rules vary by type. Parthenocarpic cucumbers require careful temperature and humidity control around fruit set. Pruning and leaf removal align canopy demand with fruiting sink strength.

Pest, disease, and disorder management: Canopy density influences humidity, temperature, and spray penetration. Training that opens fruit zones reduces infection risk and improves coverage. In grapes, leaf removal around clusters reduces Botrytis. In apples, spur thinning and branch renewal reduce scab inoculum retention. In berries, cane thinning lowers cane blight incidence. Physiological disorders link to

exposure. Sunburn in apples and grapes increases with sudden exposure during heat events. Plan summer pruning before heat waves and avoid aggressive late defoliation. In citrus, skirt lifting reduces fruit rot by keeping fruit away from splashing rain. In greenhouse vegetables, timely deleafing and sanitation lower whitefly and botrytis risk while maintaining photosynthetic capacity.

Economics and risk: Training and pruning affect both revenue and cost. They influence precocity, packout, and consistency, which determine price and volume. They also set annual labour needs. High-density systems spend more on establishment but generate earlier returns. Poorly executed training adds hidden costs through rework, alternate bearing, and quality penalties. Risk management starts with simplicity. Choose systems that match vigour, climate, and water supply. Avoid complex, multi-leader forms in sites with limited skilled labour. Use rootstocks that keep vigour within the control range. Calibrate pruning severity to avoid excessive regrowth. Align canopy with irrigation and nutrition to prevent imbalances.

Common mistakes and troubleshooting: Delaying training in the establishment years is costly. Unchecked shoots become large limbs that are hard to correct. Early selection and removal prevent this. Overly heavy dormant pruning can trigger vigorous regrowth and shading. Avoid significant cuts unless needed for structural renewal. Use staged renewal over multiple years. Neglecting summer shoot management leads to dense canopies and poor colour. Light summer interventions reduce winter workload and improve fruit exposure. In grapes, retaining too many buds produces crowded canopies and disease problems. Use pruning weights or simple vigour observations to set bud numbers. In tomatoes, excessive deleafing reduces assimilation and causes blossom end rot due to imbalanced transpiration. Follow leaf count rules and remove leaves gradually.

Climate resilience and sustainability: Canopy design interacts with heat, radiation, and wind. Narrow walls dissipate heat faster and reduce sunburn in some conditions. Planned shade from retained leaves around clusters can protect fruit during heat waves. Summer pruning should avoid exposing sensitive fruit to hot spells. Water scarcity increases the value of efficient canopies. Balanced pruning reduces nonproductive growth and water demand. Canopies that ventilate well reduce disease pressure and can lower fungicide inputs. Planar forms improve spray efficiency and minimise drift. Mechanisation and robotics require simple, repeatable structures. Training systems that present transparent walls or rows enable machine vision and end effectors. Even partial mechanisation of hedging or pre-pruning can reduce labour peaks.

Conclusion

Training and pruning are strategic levers in horticulture. They shape structure, balance vigour and crop load, and drive light capture and distribution. They also create the microclimate that determines disease risk and fruit quality. The best systems are simple, repeatable, and matched to

vigour and climate. They standardise tasks, enable mechanisation, and support sensing and data use. They deliver early yields in high-density orchards, uniform ripening in vineyards, and stable weekly harvests in greenhouses. Successful programs start early. They establish the framework in the first years and continually renew it with fruitful wood. They use light, exposure, and leaf area to guide decisions. They integrate with rootstock choice, irrigation, and nutrition. They avoid heavy corrective cuts by relying on steady, modest renewal. They manage risk by aligning system complexity with labour skills and by planning seasonal passes. Future progress will come from better measurements and simpler forms. Planar canopies and standardised units will support automation. Sensor feedback will fine-tune exposure in real time. Climate resilience will depend on dynamic canopy control that protects fruit during heat or rain events. The core principles will remain. Build the structure that the plant and the market need. Maintain balance every year. Renew fruiting wood without creating excess vigour. When growers follow these rules, training and pruning deliver consistent yield, high quality and durable profit-ability.

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The Golden Threads of Assam: Why Muga Silk is Irreplaceable

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Abstract

Muga silk, produced exclusively by the silkworm *Antheraea assamensis* in Assam, is celebrated for its golden luster, durability, and cultural symbolism. Its sheen deepens with age, making it unique among natural fibres. This article explores muga's material qualities, cultural roots, and socio-economic significance, while also highlighting the challenges of climate change, deforestation, and market pressures. Safeguarding this "golden silk" requires conservation, innovation, and community empowerment.

Introduction: The Fabric That Shines Forever

Muga silk, produced by the saturniid silkworm *Antheraea assamensis*, is one of the world's rarest natural fibres. Its golden-yellow shine is not the result of dyes but an intrinsic property of the cocoon. Uniquely, this glow becomes richer with age, even after repeated washing, a feature highlighted in material studies of non-mulberry silks (Wang *et al.*, 2015). Along with exceptional strength and durability, this brilliance has made muga both a cultural emblem and an economic asset in Northeast India (Hussain *et al.*, 2024). Genomic research shows that *Antheraea assamensis* silk proteins contribute to muga's durability, tensile strength, and pigmentation (Dubey *et al.*, 2024). Its rearing depends on Assam's ecology, particularly host plants Som (*Persea bombycina*) and Soalu (*Litsea monopetala*). Climate modelling indicates that host-plant availability and local microclimates directly affect cocoon quality, raising concerns under climate change (Sarma *et al.*, 2025). Together, these biological and ecological factors make muga a fabric unlike any other. Recent innovations such as genomic editing and stress-resilient host-plant cultivation are being explored to secure muga's future (Dubey *et al.*, 2024). As one of the few silks with geographical indication (GI) status, it represents not only biological uniqueness but also regional identity and pride (Hussain *et al.*, 2024).

Woven into Assam's Heritage: Muga silk has been interwoven with Assamese culture for centuries, once reserved for royalty during the Ahom dynasty and still central in weddings, festivals like bihu, and rites of passage. Traditional attire such as the mekhela chador carries deep cultural symbolism and identity. Community weaving practices also reflect distinct motifs and craftsmanship, reinforcing pride and heritage (Chakravorty *et al.*, 2015; Deb, 2024). Beyond ceremonial use, muga has been a marker of social prestige and a symbol of assamese resilience,

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passed down through generations as treasured heirlooms (Gogoi *et al.,* 2017). Its continued presence in both rural households and modern assamese fashion underscores its dual role as heritage and livelihood (Das, 2021). These traditions highlight that muga is not just fabric, but a cultural heirloom. Oral traditions, folk songs, and local rituals often mention muga as a symbol of prosperity and purity, further embedding it into assamese identity (Chakravorty *et al.,* 2015). Modern designers are also experimenting with blending muga into contemporary apparel and accessories, keeping its heritage relevant to younger generations (Das, 2021).

The Silkworm's Secret and What Makes Muga Unique: The uniqueness of muga silk lies in its source the silkworm *Antheraea assamensis*, which feeds on Som and Soalu. Studies confirm Som enhances cocoon quality, while combined diets improve rearing success (Borpuzari *et al.,* 2020; Jigyasu *et al.,* 2023). Beyond biology, muga's fibre structure gives it high tensile strength, moisture absorbency, stain resistance, and biodegradability, positioning it as one of the strongest natural silks (Poluri *et al.,* 2024). Its intrinsic golden pigment, natural UV resistance, and long-lasting sheen set it apart. Research shows muga absorbs up to 85% of harmful UV radiation, protecting both fabric and wearer (Gogoi *et al.,* 2017). These properties explain why muga is both a traditional treasure and a material of interest for future applications. Researchers are investigating muga's potential use in biomedical fields such as sutures and tissue engineering due to its strength and biocompatibility (Poluri *et al.,* 2024). The silk's thermal stability also makes it suitable for high-performance textiles, expanding its relevance beyond fashion into technical industries (Wang *et al.,* 2015). Table 1 highlights the key properties and cultural significance that set muga silk apart.

A Thread of Livelihood: Muga sericulture is vital to rural livelihoods in Assam, especially for women who manage rearing, reeling, and weaving. In some areas, it contributes up to 40% of household income, providing economic independence alongside agriculture (Goswami *et al.,* 2015; Gogoi *et al.,* 2017). Cooperative models and self-help groups have improved quality control, productivity, and market access (Das, 2021). Beyond direct income, participation in muga sericulture strengthens local knowledge networks and intergenerational skill transfer, preserving traditional techniques while fostering innovation (Deb, 2024). The sector also provides opportunities for women's entrepreneurship, with some establishing small-scale weaving units that supply regional and national markets (Chakravorty *et al.,* 2015). Thus, muga is both an economic activity and a form of cultural continuity.

In addition, government training programs and NGO-led initiatives are equipping farmers with modern disease management and climate adaptation skills (Hussain *et al.,* 2024). With growing global demand, muga has the potential to support rural tourism by offering visitors immersive experiences in rearing and weaving practices (Sarma *et al.,* 2024).

Table 1: Key distinctive properties and significance of muga silk

Aspect	Findings	Source
Golden lustre	Natural yellow-gold colour, deepens with age and washing	Wang *et al.,* 2015; Gogoi *et al.,* 2017
Durability	High tensile strength and resistance to weathering compared to mulberry and eri silks	Wang *et al.,* 2015; Poluri *et al.,* 2024
Cultural role	Worn in assamese weddings and rituals; symbol of pride	Chakravorty *et al.,* 2015; Gogoi *et al.,* 2017
Livelihood	Provides income for rural households, especially women	Goswami *et al.,* 2015; Das, 2021; Deb, 2024
Climate sensitivity	Rearing depends on som and soalu host plants, vulnerable to climate change	Borpuzari *et al.,* 2020; Sarma *et al.,* 2025

From Assam to the World: Challenges and Opportunities: Today, muga is gaining attention in global luxury and sustainable fashion markets as "India's golden silk" (Sarma *et al.,* 2024). However, its survival faces challenges. Even small temperature increases reduce cocoon weight and silk yield (Sarma *et al.,* 2025). Deforestation, pests, and competition from synthetics further threaten its sustainability (Singh et al., 2024). Global reports also note that the limited geographic range of *Antheraea assamensis* makes muga particularly vulnerable compared to mulberry or eri silk (Hussain *et al.,* 2024). Strengthening entrepreneurial initiatives in sericulture, such as start-ups and youth-led enterprises, can create fresh opportunities for Assam's silk sector (Sarma *et al.,* 2024). Still, opportunities exist. Eco-tourism, traceable product lines, and collaborations with fashion brands can build fairer supply chains. With policy support and conservation, muga could stand as both a heritage fabric and a sustainable global luxury. Digital platforms are now helping artisans connect directly with international buyers, bypassing exploitative middlemen and ensuring better returns (Das, 2021). If integrated into global sustainability campaigns, muga could become a flagship example of how traditional textiles align with eco-conscious lifestyles (Sarma *et al.,* 2024).

Conclusion: More Than a Fabric

Muga silk is more than a textile, it is Assam's living legacy, rooted in biology, nurtured by ecology, and sustained by tradition. Protecting it means combining science, conservation, and fair markets so that Assam's golden silk continues to shine for generations to come. With proper policy support, skill development, and international branding, muga can emerge not only as a regional heritage fabric but also as a global symbol of sustainable luxury. Encouraging cross-sector collaborations between scientists, artisans, and fashion houses will be key to driving innovation while respecting tradition, and by safeguarding its ecological foundations and cultural significance, muga can inspire a broader movement toward heritage-based sustainability worldwide.

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Niger: The Resilient and Underrated Oilseed of India

Koya Madhuri Mani, A. Uma Maheswari and Nagender G.

Introduction

When you think of oilseeds in India, you might picture mustard fields in full bloom or sunflower heads turning toward the sun. But tucked away in the hilly regions and tribal belts of our country grows a small but mighty crop Niger (*Guizotia abyssinica*). This hardy, rain-fed oilseed has been cultivated in India for centuries, valued for its nutritious oil, resilience in poor soils, and ability to grow where most other crops fail. Despite its modest presence in the market, niger plays a vital role in rural livelihoods, especially among small and marginal farmers. Niger is mainly grown in the *Kharif* season sown with the arrival of the southwest monsoon (June-July) and harvested in October-November.

Major growing states include:

- ✓ Odisha
- ✓ Chhattisgarh
- ✓ Madhya Pradesh
- ✓ Maharashtra
- ✓ Andhra Pradesh
- ✓ Jharkhand

It thrives in light soils, even sandy and degraded lands, and requires no irrigation in most cases. In fact, it's often grown on hill slopes and uplands where other crops simply won't survive.

Cultivation Practices

A fine seedbed is ideal. Since the seeds are tiny, deep ploughing isn't needed one or two ploughings and harrowings are usually enough.

Time: June-July (with monsoon)

Spacing: 25-30 cm between rows

Seed Rate: 3-4 kg ha^{-1}

Niger isn't a heavy feeder, but a light dose of nitrogen and phosphorus boosts yields. Organic manure is often used in tribal farming systems. A single hand-weeding 20-25 days after sowing is usually sufficient. Niger is relatively pest-free, though occasional leaf-eating caterpillars and powdery mildew may appear. The crop is ready in about 100-110 days. Harvest when most flower heads turn brown; delay can cause shattering losses.

The Oil and Its Uses: Niger seeds yield 30-40% pale yellow oil with a mild nutty taste. The oil is:

- ✓ Used for cooking in rural households
- ✓ Employed in making soaps, paints, and lubricants
- ✓ Rich in linoleic acid, making it nutritionally beneficial

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Table 1: Recommended varieties in India

Variety Name	State(s) Recommended	Duration (Days)	Special Traits
IGP 76	Chhattisgarh, Odisha, Maharashtra	100-105	High yield, medium seed size
GA 10	Gujarat, Maharashtra	105-110	High oil content (~38%), drought tolerant
RCR 18	Chhattisgarh, Madhya Pradesh	95-100	Early maturity, suitable for rainfed
NB 21	Odisha, Jharkhand, West Bengal	100-105	Good seed yield, lodging resistance
JNC 6	Andhra Pradesh, Telangana	95-100	Tolerant to powdery mildew
Ootacamund 8	Tamil Nadu (hilly areas)	110-115	Suited for cooler climates
RCR 728	Chhattisgarh, MP, Odisha	100-105	High oil yield, uniform maturity

- ✓ The seed cake left after oil extraction is an excellent cattle feed.

Government Support and Subsidies

In India, niger comes under the National Food Security Mission - Oilseeds and various state agricultural programs. Farmers can benefit from:

Seed Minikits: Free or subsidized certified seeds for higher yield varieties.

Input Subsidies: Assistance for fertilizers, plant protection chemicals, and bio-fertilizers.

Farm Machinery Subsidy: Under schemes like Sub-Mission on Agricultural Mechanization (SMAM), small farmers can get 40-50% subsidy on seed drills, weeders, and threshers.

Minimum Support Price (MSP): Declared annually by the Government of India (e.g., MSP for niger in 2024-25 is around ₹7,400 quintal^{-1}).

Cluster Frontline Demonstrations: Conducted by Krishi Vigyan Kendras (KVKs) to promote improved cultivation techniques.

Why Niger Matters Today

In an era of climate change, niger's resilience thriving on poor soils with minimal inputs makes it a smart crop for rainfed and tribal areas. Promoting its cultivation not only diversifies farmer income but also preserves a part of India's agricultural heritage. With better market linkages, value-addition, and awareness, this small black seed could very well reclaim its rightful place in the Indian oilseed basket.

Unearthing Potato Perfection: A Guide to the High Yielding Varieties

Priyanka Deka and Pabitra Kumar Nath

Introduction

Potato belongs to the solanaceae family (nightshade family) and botanically known as *Solanum tuberosum*. Potato is one of the most important crops as they are high yielding and nutrient rich crop that provides affordable energy and essential nutrients to a large population globally. Potatoes adaptability to various climates and market demands, coupled with their nutritional value, makes them a valuable crop for food security and economic empowerment. Since, potatoes have high demand and market in developing countries like India, the cultivation of potato plays a crucial role in providing cash starved rural households with income, particularly in regions where land is limited and labour is abundant. In the list of top potato producing countries in the world, India rank 2nd in terms of production after China. In the early 17th century the Portugese colonials introduced this crop in India from Europe.

Potato is one of the major crops in Assam and ranks third in terms of area (1.40 lakh ha^{-1}) after rice and rapeseed mustard being widely cultivated vegetable crops in Assam. But the average state yield is only 7-10 t ha^{-1} compared to national average of 25.79 t ha^{-1}.

The crop requires cold temperature, adequate moisture and well drained soil for its growth and it sowing time is best from mid October to November. There are different varieties of potato which were developed by Central Potato Research Institute and few varieties are suitable for Assam agroclimatic conditions since a study was undertaken under APART, Project at Krishi Vigyan Kendra, Nagaon, Assam Agricultural University.

Conclusion

Many potato varieties have been developed in the country during the past years. Selection of a proper variety for a particular region is of outmost important to gain the maximum yield. The crop is very sensitive to climate changes so while selecting the variety it is a very crucial step. Since the crop is also very much affected by pest and disease selection of a resistant variety is also very important.

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Table 1: Different varieties of Potato

Variety	Duration	Productivity	Morphological features	Disease resistance	Special attributes
Kufri Pukhraj	70-90 days	350-400 q ha^{-1}	Flower white. Tuber yellow, ovoid with shallow medium eyes and yellow flesh. Sprout is purple in colour.	Resistance to early blight, moderately resistant to late blight	Early bulker, suitable for low input ecosystem. Free from after cooking discolouration.
Kufri Jyoti	90-110 days	250-300 q ha^{-1}	Flower is white. Sprout Red-purple in colour. Tuber is white-cream, ovoid with shallow eyes and flesh is cream in colour.	Moderately resistant to early and late blight.	Early bulker and slow rate of degeneration. Free from after cooking discolouration. Good for processing.
Kufri Himalini	90-110 days	300-350 q ha^{-1}	Flower red-violet. Tuber is white- cream and ovoid with medium deep eyes. Flesh yellow colour. Sprout is pink in colour.	Moderately resistant to late blight.	Free from after cooking discolouration.
Kufri Chipsona 3	90-110 days	300-350 q ha^{-1}	Tuber is white cream in colour. Shape is ovoid with shallow eyes and white flesh. Flower is white. Sprout is Red- purple.	Resistant to late blight	Suitable for making chips and French fries. Free from after cooking discolouration. Low reducing sugars and low phenols, high dry matter.
Kufri Khyati	70-90 days	250-300 q ha^{-1}	Flower white. Tuber is white- cream in colour, ovoid with medium deep eyes and white cream flesh. Sprout Red- purple colour.	Resistant to early and late blight.	Early bulker. Free from after cooking discoloration.
Kufri Surya	70-90 days	250-300 q ha^{-1}	Flower Red-violet. Tuber colour is white- cream, oblong with shallow eyes and flesh colour is cream. Sprout is Red-purple in colour.	Not Applicable	Heat tolerant, tolerant to hopper and mite burn. Free from after cooking discoloration. Good for making French fries.
Kufri Mohan	90-110 days	350-400 q ha^{-1}	Tuber is Oval shaped, Tuber colour is white cream and flesh white in colour.	Moderately resistant to late blight	>90% marketable tuber yield under optimum agronomical practices, Shallow eyes resulting in lower peeling losses
Lady Rosetta	70-90 days	250-300 q ha^{-1}	Flower red-violet. Tuber is round and red in colour. Flesh colour of tuber is light yellow. Sprout pink.	-	It is a specialist crisping variety. It has high dry matter and low reducing sugars.
Yusi Maap	70-90 days	300-350 q ha^{-1}	Tuber is oval shaped and red in colour and the flesh colour is white-cream. Sprout Red-purple in colour.	Moderately resistance to early blight, late blight and Bacterial wilt.	Tolerant to drought, heat and salinity. Rich in Fe, Zn and Vitamin C. Can be used as table as well as processing purpose.

Empowering Farmers through Regulated Markets: Advancing Fair Trade Practices and Enhancing Rural Incomes

Rishi Kumar S., Santhosh S., Sarala M., Sasi R., Subhashini R. and R. Suresh

Introduction

The agricultural sector is the backbone of many economies, especially in India, where a majority of the rural population depends on farming for their livelihoods. However, farmers have historically faced challenges such as unfair pricing, exploitation by intermediaries, and limited market access. Regulated markets, established to oversee and standardize the buying and selling of agricultural produce, play a crucial role in addressing these challenges. By promoting fair trade practices and transparency, these markets empower farmers to secure better incomes and contribute to rural economic development. This article explores how regulated markets aid farmers, focusing on economic benefits, fair pricing, and government support enhancing their livelihoods.

Background on Regulated Markets

Regulated agricultural markets are government-sanctioned platforms where agricultural produce is traded under a set of rules and oversight mechanisms aimed at protecting the interests of farmers. These markets differ significantly from unregulated or open markets where pricing and trading practices are often opaque, leading to farmer exploitation. Key features of regulated markets include price control mechanisms, quality standards, transparent auctions, and infrastructure support such as storage and weighbridges. In India, the Agricultural Produce Market Committee (APMC) Act regulates these markets, establishing market yards (mandis) to create an organized trading system. As of March 31, 2021, there were approximately 6,920 regulated mandis across the country, providing a formal marketplace for farmers to sell their produce directly or through licensed traders, thus ensuring more standardized and fair trade conditions. The introduction of digital platforms like the National Agriculture Market (e-NAM) has revolutionized these traditional systems by integrating over 1,500 regulated markets from 23 states and four union territories, enabling electronic auctions and interstate trading, significantly enhancing market outreach for farmers.

How Regulated Markets Empower Farmers

Regulated markets empower farmers by providing them with greater market access, transparent pricing, and opportunities to negotiate competitive prices for their produce. Unlike unregulated systems where farmers often face predatory

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middlemen who exploit information asymmetry, regulated markets offer a structured environment where farmers' produce is auctioned either physically or digitally, ensuring fair price discovery. The e-NAM platform, for example, has registered over 1.75 crore farmers and facilitated trade volumes worth nearly Rs 2.79 lakh crore, demonstrating the scale at which regulated electronic markets empower farmers by offering a competitive and transparent trading ecosystem. Additionally, market infrastructure such as assaying labs, warehouse facilities, and unified licenses for traders reduces transaction costs and delays, further benefiting farmers. By improving transparency and reducing informational barriers, farmers gain confidence and better control over their earnings, ultimately boosting rural incomes.

Fair Trade Practices in Regulated Markets

Fair trade practices in regulated markets ensure ethical, equitable trade relationships and transparency in price setting. These markets uphold principles such as transparency in auctions, equitable access for small and marginal farmers, and standardization of quality and weights to prevent malpractice. With the implementation of regulated markets, farmers benefit from reduced price volatility, fewer exploitative intermediaries, and timely payment settlements. The introduction of single-point levy and unified licensing reduces redundant fees and opens greater market opportunities for traders, thus creating a competitive environment that benefits farmers. Moreover, digital e-trading platforms under regulated markets promote fair competition by increasing the number of bidders per lot, which raises prices and reduces collusion among traders. Studies have shown e-markets increasing farmer prices by approximately Rs 65 quintal^{-1} and reducing price variability compared to non-e-markets.

Economic Benefits for Farmers and Rural Communities

The economic benefits to farmers and rural communities due to regulated markets are substantial. By reducing the role of middlemen, regulated markets allow farmers to retain a greater share of the consumer price, thus directly increasing their incomes. For instance, the e-NAM initiative in Karnataka boosted farmer incomes by 38% in nominal terms between 2015-16, while improving price transparency and market access. In addition to income improvements, regulated markets stimulate rural economies through job creation and increased business opportunities in allied sectors like transportation, storage, and input supply. Enhanced market infrastructure attracts investment and fosters value addition, which can improve income stability and economic resilience in farming communities. Furthermore, government schemes such as the Rashtriya Krishi Vikas Yojna (RAFTAAR) and Agriculture Infrastructure Fund (AIF) facilitate the development of regulated market infrastructure, thereby supporting long-term rural economic growth.

Reduction of Intermediaries and its Impact

Traditional agricultural markets in India have

been characterized by numerous intermediaries - arhatiyas or commission agents - who often charge high commissions and manipulate prices to their advantage, reducing the share of farmers in the final consumer price. Regulated markets minimize these intermediaries' influence by ensuring transparent auctions and restricting the role of commission agents through licensing and market regulations. By reducing the layers of intermediaries, farmers can negotiate directly or through licensed traders, which leads to higher realized prices and faster payments. Digitalization of trading further curbs malpractice by reducing physical dependency on middlemen. This shift has the effect of increasing the share of farmer's income in the consumer rupee and cutting exploitative fees that traditionally cut into farmer earnings.

Role of Government and Policy Support

Government policies are pivotal to the success and expansion of regulated markets. The Indian government supports regulated markets through legislative frameworks, infrastructure funding, and digital initiatives like e-NAM that integrate traditional mandis into a pan-India electronic trading platform. The government has undertaken several reforms, especially post-COVID-19, to facilitate direct marketing of produce, enable inter-state trade, and promote contract farming. Amendments to the Essential Commodities Act and APMC regulations are designed to reduce barriers, increase market competition, and safeguard farmer interests. Financial assistance has been provided for the modernization of mandis, including grants for infrastructure like warehouses, cold storage, and assaying labs. Unified Single Licensing has been introduced to facilitate cross-market trading. Additionally, the creation of Market Yards of National Importance aims to streamline interstate trade for better farmer price realization.

Conclusion

Regulated markets have emerged as a critical mechanism to empower farmers by advancing fair trade practices and significantly enhancing rural incomes. Through transparent pricing, reduction of intermediaries, policy reforms and digital integration via platforms like e-NAM, these markets support equitable and efficient agricultural trade, benefitting millions of farmers across India. While challenges such as bureaucratic hurdles and limited market density persist, continuous government support and technological advancements promise a future where farmers can fully realize their produce's value. Strengthening regulated markets is not only vital for farmer prosperity but also essential for sustainable rural economic development and food security.

Enhancing India's Agricultural Finance via Digital Transformation and Comprehensive Credit Assistance

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Abstract

India's economic growth is mostly dependent on the growth of agriculture, more specifically when it comes to improvement of the lives of people in rural areas and making sure there is adequate amount of food. But, when small and marginal farmers are not able to get timely and affordable institutional finance to boost agricultural productivity is a big problem. The Government of India (GoI) has introduced a number of reforms and programs to make it easier for farmers to get loans, such as the Kisan finance Card (KCC), the Modified Interest Subvention Scheme (MISS), and the new AgriSURE Fund and Kisan Rin Portal (KRP). This study looks at these important projects, describe how they contribute agricultural modernization and financial inclusion, and evaluates their results.

Introduction

Agriculture plays a vital role in India's economy. 54.6% of the population is engaged in agriculture and allied activities (Census 2011), but the sector has low productivity because it doesn't have easy access to technology and capital. Small and marginal farmers, who make up more than 86.2% (2015-16 Agricultural Census) of the farming population, are often the ones who face difficulties to get loans. The Government of India has made a number of financial interventions through the Department of Agriculture and Farmers' Welfare (DA&FW) to close this gap by providing financing that is timely, easy to get, and not too expensive. This review's goal is to see how well these programs have changed the way banks lend money to farmers in India. Kisan Credit Card (KCC) helps more people get facilities and benefits to financial services. The Kisan Credit Card (KCC) was launched in 1998 with the objective of providing short-term loans to help farmers be more productive and it was a revolutionary program. Over time, its area of responsibility has grown to include fisheries, animal husbandry, and other related fields. As of March 31, 2024, there were 7.75 crore active KCC accounts, and the total amount of loans that were still owed was ₹9.81 lakh crore.

Key Achievements

- ✓ Expansion of Allied Activities: The diversification of rural revenue streams in 2018-19 was

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supported by the expansion into fisheries and animal husbandry.

- ✓ Progressive Annual Growth: Operating accounts and outstanding amounts are increased by 5.58% and 10.85%, respectively, between 2022-2023 and 2023-2024.
- ✓ Collateral-free loans, which have been raised to ₹1.6 lakh, reduce dependency on unofficial non-institutional lending.
- ✓ By facilitating timely input purchases, ensuring that farmers receive working finance on time, and reducing their dependency on high-interest non-institutional sources, the KCC has been instrumental.

Modified Interest Subvention Scheme (MISS): Lowering the Cost of Credit

- ✓ The MISS provides short-term crop loans with lower interest rates to guarantee affordability of small and marginal farmers. Under this plan, farmer have to pay 7% interest per year for availing credit upto 3 lakhs rupees.
- ✓ Rebate for on-time payment: Farmers who repay on time receive an additional 3% subvention, bringing down the interest rate to 4% per year.
- ✓ Credit to this group grew by 19.82% annually between 2022-2023 and 2023-2024.
- ✓ Ground Level Credit (GLC) in agriculture increase at a compound annual growth rate (CAGR) of 12.98% from ₹8.45 lakh crore in 201415 to ₹25.49 lakh crore in 202324, with MISS playing a significant role in this growth.
- ✓ Subsidy Support: Between 2014-15 and 2024-25 in last 10 years, the Indian government disbursed over ₹1.6 lakh crore in subsidies as of February 2025.
- ✓ Increase in Credit Distribution: Small and marginal farmers received 57% of credit in 2023-2024, in comparison to 41% in 2014-15.

AgriSURE Fund: Promoting Innovation in Agriculture via Start-ups

To support the agri-tech companies to give emphasis the value of innovation in modern agriculture, the AgriSURE Fund was created. The entire blended capital fund was ₹750 crores, with equal contributions from the Govt. of India, NABARD, and private investors.

Structure and Focus

- ✓ Through the Direct Funding Scheme up to ₹25 crores can be invested directly in start-ups
- ✓ Agriculturally related projects under the Fund of Funds (FoF) Scheme received an investment of ₹450 crores was supported by AIFs which are registered with SEBI.
- ✓ By concentrating on industries like biotechnology, renewable energy, food processing, and agritech, AgriSURE is poised to support over 85 start-ups over the next ten years. The fund, managed by NABVENTURES Ltd., supports agricultural value chains and rural businesses by ensuring compliance and strategic support.

Kisan Rin Portal (KRP): Digitizing Agricultural Credit Delivery

One of the most important phases in the digitization of the agricultural finance system is the

KRP, which was unveiled in September 2023. It streamlines the MISS-KCC claim processing process, which was previously manual and inefficient.

Features and Benefits

Real-time Claim Submission: This expedites farmers' access to financing and helps banks avoid delays.

Inclusive Access: Promotes loans for crops, dairy, poultry, beekeeping, and fisheries.

Widespread Adoption: 449 banks and 1.89 lakh branches were integrated as of February 2025.

Digital Mapping: Over 5.99 crore farmers have been mapped by KCC-MISS.

System Integration: Interfaces with platforms like PM-Kisan, UIDAI, and PMFBY, as well as upcoming integrations with AgriStack, Bharat Pasudhan, and the National Fisheries Digital Platform, aim to create a single Agri Credit Stack.

With more than 630 master trainers and ongoing support via LMS platforms, phone calls, and digital outreach, the portal is supported by a strong training environment. Future Direct Benefit Transfers (DBT) through PFMS will increase the efficiency of subsidy distribution.

Discussion and Policy Implications

These credit initiatives show a thorough approach to agricultural development:

Financial Inclusion: By making credit more accessible to small and marginal farmers, these initiatives increase resilience and reduce dependency on non-institutional and unofficial lenders.

Technology Adoption: Automation, climate-smart agriculture and precision farming are adopted rapidly to start up support and credit availability.

Efficiency and Transparency: KRP's digitization ensures more accurate to target subsidy, enhances governance, and reduces fraud.

However, there are still some issues:

Digital Divide: To effectively use KRP and fintech tools, farmers must have to be literate and have access to the internet.

Bottlenecks within the institution: The efficiency of delivery may be hindered by irregularities in data processing and hold-ups in bank-side claim approvals.

Sustainability in Lending: It is very much vital to make sure that subsidized lending leads to profitable investments rather than excessive debt.

Conclusion: Moving Toward an Inclusive, Tech-Enabled Agricultural Economy

With the introduction of the agricultural finance, KCC, MISS, AgriSURE, and KRP in India has changed dramatically, advancing the development of a more creative, effective, and inclusive rural economy. These programmes not only eliminate financial gaps but also pave the way for environmentally friendly and technologically assisted farming practices. By integrating state policy, digital infrastructure, and private sector innovation, India is creating a resilient agricultural sector that supports rural entrepreneurship, empowerment of small and marginal farmers, and significantly contributes to the nation's food and

economic growth, stability and security.

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Sustainable Aquaculture: Farm-Made Carp Feeds

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Introduction

The growing population increased the demand for nutritionally adequate food. Fish is one of the staple food used by human beings because of its nutritional quality. The aquaculture sector production is increasing day by day and reached 130.9 million tonnes by the year 2022 (FAO, 2024). Polyculture system of carps involves rearing silver carp, grass carp, and common carp (exotic carps) alongside with Catla, Rohu, and Mrigal (Indian main carps). Indian farmers majorly culture the carps in earthen ponds using traditional methods. Which involves feeding the fry of carps with the mixture of rice bran and groundnut oil cake. For fish farmers, one of the biggest expenses is feed costs. Feed cost around 60% of the operational cost and there are some commercial carp culture feeds are available in the market. When raising carp in a nursery, nutrition is essential to their growth and survival. Lack of access to high-quality feed is among the primary causes of the low growth and survival rates, which reduce the profitability of carp nursery rearing. Some commercial feeds are available in the market which contains fishmeal and other protein sources some vitamin-mineral mixtures added to the feed. The nutrients namely protein, lipid, vitamins and minerals are essential in carp diets for growth performance and survival. For one or other reasons like 1) feed cost 2) availability of feed in small quantities 3) accessibility of the diets for fish farmers in isolated areas, farmers cannot afford to purchase the commercial diets because of some of these reasons. Farm made feed is only available option for farmers to meet the feed requirement of carps. However only feeding mixture of rice bran and groundnut oil cake in 1:1 ratio doesn't fulfill the nutritional requirement of fish.

Scientist from ICAR-CIFA conducted a trial on feeding traditional feed i.e., mixture of rice bran and groundnut oil cake 1:1 ratio and farm made feed to carps. Prepared farm made resulted in better growth performance and survival. Fish farmers can utilize the locally available feed ingredients like wheat bran, maize meal, soybean meal and cottonseed meal. These are all plant protein sources which are locally available and are also cheaper than fish meal. So preparation of farm made feed using this ingredient significantly reduces the cost of feed, also fulfill the nutritional requirements of carps.

Preparation of farm made feed

How to calculate feed ingredients proportions to make 1 kg of feed

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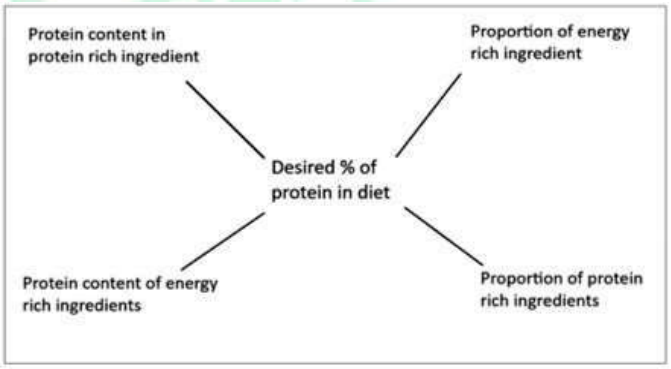
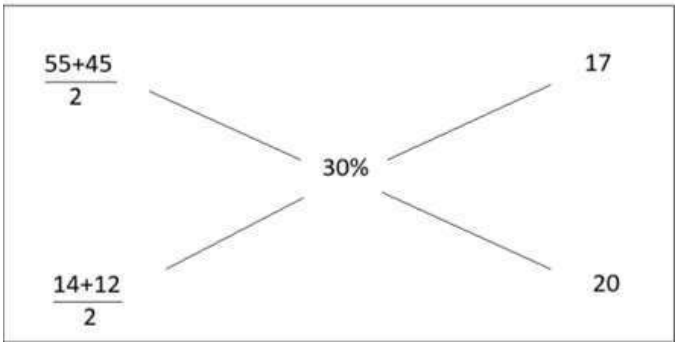
Table 1: Some locally available fish feed ingredients

Ingredients	Crude protein (%)	Crude lipid (%)	Crude fiber (%)	Ash (%)
Rice bran	12-16	12-14	8-12	5-8
Wheat flour	8-11	2-4	1-4	1-3
Groundnut oil cake	40-45	6-8	8-9	4-5
Soybean oil cake	44-48	1-2	4-5	5-6
Mustard oil cake	25-38	6-9	10-16	10-12
Soyabean meal	50-55	1-2	4-5	5-8
Corn meal	10-12	4-5	3-4	1-2
Sunflower oil cake	38-42	3-6	10-15	6-7
Bajra	8-15	2.7-7.1	2.6-4	1.6-2.4
Barley grains	8-10	2-3	4-6	2-3
De-oiled rice bran	15-18	12-14	8-12	5-8
Rice polish	12-18	12-14	8-12	5-8

Feed can be prepared using some ingredients, such as rice bran, groundnut cake, soybean meal, rice bran and corn meal. The amount of each ingredient can be calculated manually using Pearson square method. Assume that 30 % protein diet is required for carps during nursery rearing. To formulate the 30% crude protein diet the quality of each feed ingredients can be calculated by following procedures,

- ✓ Divide the ingredients based on protein content as, protein rich ingredient Groundnut oil cake and Soybean meal (more than 20% Crude protein) and energy rich ingredients rice bran and corn meal (less than 20% protein).
- ✓ Requirement of protein in diet 30%. Make a square or draw a square add protein rich ingredients on left upper side of square, energy rich ingredient on left lower side of square, required protein level in the fish diet in middle of square, proportion of energy rich ingredient required on right upper side of the square and proportion of protein rich ingredient on right lower side of square.
- ✓ Now add protein levels of soyabean meal and groundnut oil cake and dived them by 2 then subtract the value from centre value which is diet protein level, we will get the proportion value, similarly for energy rich ingredients.
- ✓ Now to calculate actual amount of each ingredient,





- ✓ Energy rich ingredient $\frac{17}{20+17} = 0.46$ and Protein rich ingredient $\frac{20}{17+20} = 0.54$
- ✓ Protein rich ingredient 46%, therefore we required 230 grams of soyabean meal and groundnut oil cake each. Energy rich ingredient 54%, we required 270 grams of rice bran and

corn meal to prepare a feed of 30% protein level in 1 Kg of fish feed.

How to make feed pellets

- ✓ Ingredients in required quantities are milled and mixed together.
- ✓ Grinding and mixing can be done using a small grinder, mixer and small grinder-cum-pulverizer.
- ✓ Add water to make a dough.
- ✓ Steam the prepared dough on a fire place with some water, to reduce any anti-nutritional factors if present.
- ✓ Let the dough cool down and now add 1-2% vitamin-mineral premix.
- ✓ Transfer this prepared dough into hand pelletizer or into a portable small pellet machine to make pellets. Use desired dice to get feed pellets
- ✓ Now sundry the prepared pellets and use in carp culture pond.
- ✓ Pellets can be crumbled by the above grinder to make small pieces for nursery and juvenile rearing.

Storage and preservation of farm made feed

- ✓ Farm made feed pellets should be used fresh as possible.
- ✓ The prepared feed can be stored for a month to two months based on the storage conditions.
- ✓ Use polythene gunny bags to store the feed pellets
- ✓ Avoid moisture contamination and seal the bags in air tight containers to keep the feed in dry condition.
- ✓ To avoid any fungal growth, sundry the feed every 15 days
- ✓ If observed any type of fungal infection, it is advised to do not use the feed to fed the fish in pond. It will affect fish growth and deteriorate the water quality as well.

Application of Farm made feeds

- ✓ Based on the fish size, finely crumbled feed can be broadcasted in the nursery pond initially for a week.
- ✓ Feed dispenser device can be used for distribution of course crumbled feed.
- ✓ To feed the grow out fish, hanging tray or hanging basket with feed pellets can be placed at different depth of water in the pond.
- ✓ Schedule the feeding time to apply the feed pellets in split dosages as per the consumption of fishes.

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Seed Vault: A Global Backup Strategy for Food Security

Hafsha R. and Punitha S. P.

Abstract

Ensuring food security in the 21st century is becoming increasingly challenging due to climate change, biodiversity decline, conflicts, and population growth. The sustainability of agriculture depends largely on conserving crop genetic resources, which are essential for breeding and adaptation. The Svalbard Global Seed Vault (SGSV), popularly known as the "Doomsday Vault," functions as a secure repository for safeguarding crop diversity. Situated in the Arctic archipelago of Svalbard, Norway, the Vault currently stores over 1.3 million seed accessions contributed by nations and institutions worldwide. This article explores the Seed Vault's establishment, location advantages, management system, contributions to global agriculture, limitations, and prospects for strengthening food security.

Introduction

Food production systems worldwide are highly vulnerable to environmental, political, and demographic pressures. Variability in climate, soil degradation, pest and disease outbreaks, and armed conflicts significantly threaten agricultural sustainability. Crop genetic diversity is a fundamental resource for plant breeders, enabling the development of stress-tolerant and high-yielding varieties (FAO, 2019). However, the loss of traditional varieties and their wild relatives diminishes this adaptive capacity. While numerous genebanks conserve these resources, many face risks from natural disasters, technical failures, or political instability. To provide an additional safeguard, the Government of Norway, in partnership with global organizations, launched the Svalbard Global Seed Vault in 2008. The facility acts as the ultimate insurance for crop genetic resources, ensuring that humanity preserves its agricultural foundation for future generations.

Origins and Purpose: The concept of creating a secure global reserve for seeds emerged in the early 2000s when scientists recognized that many existing genebanks lacked reliable protection. Past experiences, such as the destruction of seed collections during conflicts in Iraq and Rwanda, demonstrated the fragility of genetic resources (Westengen *et al.*, 2020).

The Vault was designed with three primary goals:

Backup storage: Maintaining duplicates of seeds from global genebanks.

Neutral access: Ensuring participation by all nations and institutions without political bias.

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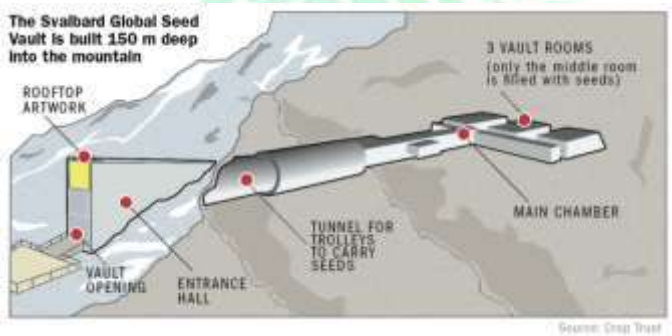
Long-term conservation: Providing an environment capable of sustaining seeds for decades or centuries.

Why Norway?

Location Advantages: The Seed Vault is located on Spitsbergen Island, about 1,300 km from the North Pole. Its position offers several benefits: stable political conditions, low geological activity, and consistently cold Arctic temperatures. The facility extends 120 meters into sandstone rock, with surrounding permafrost serving as a natural cooling system.



Storage and Infrastructure: Seeds are stored at -18 °C in sealed foil packages under low humidity conditions, which greatly extend their viability. The Vault has three storage chambers with a combined capacity of 4.5 million accessions. Even in case of power failure, the permafrost ensures passive cooling. After water intrusion was detected in 2016, the Norwegian government upgraded the infrastructure with new drainage systems and a waterproof tunnel, making it more resilient to climate change impacts (The Guardian, 2017).

Governance and Management: The Seed Vault is managed through a tripartite collaboration:

- ✓ Government of Norway responsible for ownership, funding, and maintenance.
- ✓ NordGen (Nordic Genetic Resource Center) oversees daily operations and seed cataloging.
- ✓ Crop Trust (Global Crop Diversity Trust) provides financial support and strategic direction.
- ✓ A "black-box system" is followed: depositors retain ownership of their seeds and only they can withdraw them. This framework encourages trust and global participation.
- ✓ As of 2025, more than 1.35 million seed samples from over 120 nations and organizations are secured in the Vault (SeedVault.no, 2025). These include contributions from:
- ✓ CGIAR centers (e.g., IRRI for rice, CIMMYT for wheat and maize).
- ✓ National programs (United States, India, Canada).
- ✓ Indigenous communities (e.g., Cherokee Nation, Peru's Parque de la Papa).

This makes the SGSV the largest collection of crop diversity ever assembled.

Case Study: ICARDA

The value of the Seed Vault was proven during the Syrian civil war. The International Center for Agricultural Research in the Dry Areas (ICARDA) lost access to its Aleppo genebank. In 2015, ICARDA became the first institution to withdraw seeds from the Vault, enabling the re-establishment of its collection in Lebanon and Morocco. After regeneration, the seeds were redeposited, demonstrating the Vault's role as an

effective backup system (Westengen *et al*., 2020).

Significance and Contributions

The SGSV strengthens global food security by:

Mitigating risks: Protecting against catastrophic loss of crop diversity.

Ensuring breeding continuity: Preserving essential material for future crop improvement.

Reducing redundancy: Providing a cost-effective central insurance system.

Symbolizing cooperation: Serving as a global emblem of collective responsibility in safeguarding biodiversity.

Limitations and Criticisms

Although highly valuable, the Vault has limitations:

Climate risks: Arctic warming may reduce the stability of permafrost.

Incomplete representation: Certain crops and regions remain underrepresented.

Dependence on primary collections: The Vault does not replace active genebanks; it only preserves deposited samples.

Policy concerns: Debates around digital sequence information (DSI) and benefit-sharing may influence future participation (FAO, 2019).

Future Directions

To maximize its effectiveness, the Seed Vault must:

- ✓ Increase representation of underutilized and local varieties.
- ✓ Strengthen infrastructure against climate-related threats.
- ✓ Improve integration between depositor databases and Vault records.
- ✓ Promote participation from local and Indigenous communities for conserving culturally significant crops.

Conclusion

The Svalbard Global Seed Vault is humanity's most ambitious effort to conserve agricultural biodiversity. While it cannot substitute for active genebanks or solve every food security challenge, it provides an irreplaceable safeguard against the permanent loss of crop genetic diversity. In an era marked by climate change and political instability, the Vault stands as a critical safety net a true backup plan for global food security.

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Biological Control: A Sustainable Approach to Rice Pest Management

M. V. Krishnaji, N. Srinivasa Rao, S. Dayakar, P. V. Ramesh Babu and T. Srinivas

Introduction

Rice is a staple food crop in India, particularly in the southern states. India is the second-largest producer of rice globally, accounting for a significant portion of the world's rice production. Rice is grown in various parts of the country, with West Bengal, Punjab, Uttar Pradesh, Andhra Pradesh and Bihar being the top rice-producing states. The crop thrives in hot and humid climates with temperatures between 22-32°C and annual rainfall of 150-300 cm. Rice is typically grown in clayey loam or loamy soil and India has a long history of rice cultivation with traditional methods still in use. Andhra Pradesh is known as the "Rice Bowl of India" and is the largest producer of rice in the country, accounting for 12% of total rice production. The state's fertile deltaic alluviums and red clay soils make it an ideal location for rice cultivation. Major rice-producing districts in Andhra Pradesh include West Godavari, East Godavari, Kakinada, Eluru, Dr. B.R. Ambdekar Konaseema, Krishna, Guntur, Srikakulam, Vizianagaram and Chittoor. The state has implemented various initiatives to promote rice cultivation, including the Andhra Pradesh State Seeds Development Corporation, which provides certified seeds to farmers.

Significance of Pest and Disease Management in Rice Crop: Pest and disease management is crucial for rice crop, as it can significantly impact yield, quality, and food security. Here are some key reasons why pest and disease management is essential:

Yield Loss Prevention: Pests and diseases can cause significant yield losses, reduce rice production and affect food security.

Quality Maintenance: Effective pest and disease management helps maintain the quality of rice grains, ensuring they are free from damage and contamination.

Food Safety: Pest and disease management ensures the production of safe and healthy rice, reducing the risk of mycotoxin contamination and other food safety hazards.

Economic Benefits: By reducing yield losses and maintaining quality, pest and disease management can help farmers increase their income and improve their livelihoods.

Environmental Sustainability: Integrated pest management (IPM) approaches can reduce the use of chemical pesticides, minimize environmental pollution and promote sustainable agriculture.

Common Pests and Diseases include brown plant hopper, green leafhopper, stem borer, and rice leaf folder, blast, sheath blight, sheath rot and bacterial leaf blight.

The Integrated Pest Management (IPM) is a holistic approach that combines physical, cultural,

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biological, and chemical controls to manage pests and diseases. Out of all approaches the biological control is highly cost effective and eco-friendly technic and having a significant role in IPM.

Biological control Rice Pest and Disease Management: Biological control plays a pivotal role in sustainable agriculture by providing an eco-friendly alternative to chemical pesticides. This approach utilizes natural enemies, such as predators, parasitoids, and pathogens, to regulate pest populations and maintain ecological balance.

Types of Biological Control

Predators: Ladybugs preying on aphids, for example.

Parasitoid Insects: Trichogramma wasps laying eggs inside pest larvae.

Pathogenic Microorganisms: Bacteria like Bacillus thuringiensis infecting and neutralizing certain pests.

Predators play a vital role in controlling rice pests, reducing the need for chemical pesticides and maintaining ecological balance. Some key predators found in rice fields include:

Ladybird Beetles: These beetles, belonging to the family Coccinellidae, prey on leafhoppers and planthoppers. Notable species include:

- ✓ ***Micraspis hirashimai:*** A common coccinellid that effectively controls hopper populations.
- ✓ ***Harmonia octomaculata:*** The larvae of this species hunt nymphs of brown planthoppers.

Ground Beetles: *Ophionea nigrofasciata*, a member of the family Carabidae, is an effective predator of rice leaf folder larvae.

Rove Beetles: *Paederus fuscipes*, belonging to the family Staphylinidae, is a voracious predator of naked eggs laid by lepidopteran defoliators on foliage.

Spiders: While not always considered primary predators, certain species like Argiope and Tetragnatha can contribute to controlling rice pests.

Dragonflies: These insects also play a role in controlling pest populations in rice fields.

It's worth noting that the effectiveness of these predators can be influenced by factors such as

Landscape specifics: The surrounding landscape can impact the abundance of insect predators in rice fields.

Farming practices: Organic farming tends to increase the population of natural enemies, including predators, compared to conventional farming methods.

Parasitoid Insects in Rice Pest Management: Parasitoid insects are natural enemies that play a crucial role in controlling rice pests. These insects lay their eggs inside or on the bodies of pest insects, where the larvae feed on the pest's internal tissues, ultimately killing it.

Examples of Parasitoid Insects

Trichogramma: A genus of tiny wasps that parasitize eggs of lepidopteran pests, such as the rice leaf folder and stem borers.

Telenomus: A genus of wasps that parasitize eggs of planthoppers and leafhoppers.

Cotesia: A genus of wasps that parasitize larvae of lepidopteran pests, such as the rice leaf folder.

Pathogenic Microorganisms in Rice Pest Management: Pathogenic microorganisms, such as bacteria, fungi, and viruses, can be used to control rice pests. These microorganisms infect and kill pests, reducing their populations and minimizing damage to rice crops.

Examples of Pathogenic Microorganisms

Bacillus thuringiensis (Bt): A bacterium that produces toxins that kill certain insect pests, such as lepidopteran larvae.

Beauveria bassiana: A fungus that infects and kills insects, such as planthoppers and leafhoppers.

Metarhizium anisopliae: A fungus that infects and kills insects, such as soil-dwelling pests.

Biological Control in Rice Pest Management: Benefits, Limitations, and Future Thrust

Key Benefits

Environmental Sustainability: Biological control reduces the reliance on synthetic pesticides, minimizing soil and water pollution, and preserving biodiversity.

Increased Crop Resistance: By promoting natural balance in ecosystems, biological control helps crops develop greater resistance to pests, limiting devastating outbreaks.

Economic Viability: In the long term, biological control can be more cost-effective than chemical pesticides, reducing farmers' dependence on expensive inputs and promoting ecological balance.

Improved Soil and Water Health: Biological control prevents water contamination from pesticide runoff and maintains soil biological activity, enhancing fertility.

Limitations

Slow action: Biological control agents can take time to act, which may not provide immediate relief.

Specificity: Biological control agents may be specific to certain pests or environments.

Mass production and delivery: Mass production and delivery of biological control agents can be challenging.

Environmental factors: Environmental factors, such as temperature and humidity, can affect the efficacy of biological control agents.

Future Thrust

Genetic engineering: Genetic engineering can be used to improve the efficacy and specificity of biological control agents.

Microbial ecology: Understanding the ecology of microorganisms can help develop more effective biological control strategies.

Biotechnology: Biotechnology can be used to develop new and effective biological control agents.

Integration with other IPM practices: Biological control can be integrated with other IPM practices, such as cultural controls and chemical controls, to achieve more effective pest management.

Research and development: Further research is needed to develop effective biological control agents and strategies for rice pest management.

By addressing the limitations and leveraging the benefits of biological control, researchers and farmers can develop more effective and sustainable pest management strategies for rice crops.

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Cultivation of Spearmint to Uplift the Socio-economic Status of Farmers

Saurabh Tiwari, Sonveer Singh, Mohit Chandra Rawat and Dipender Kumar

Introduction

Spearmint (*Mentha spicata*) belongs to family Lamiaceae. Spearmint is perennial type mint crop which is grown for its quality oil. It has shown great potential as a high-value cash crop that can significantly uplift the socio-economic status of farmers, especially in regions with suitable climates. The essential oils derived from spearmint are in demand across various industries, including food and beverages, pharmaceuticals, cosmetics, personal care, medicinal such as therapeutic uses and aromatherapy. Let's explore the various aspects of cultivating spearmint and its potential benefits for farmers. For farmers Spearmint offers high yields of both herb and essential oil with an ideal balance of Carvone and limonene. By providing farmers with high-yielding and high-quality varieties, CIMAP contributes to increased productivity and profit-ability, strengthening the livelihoods. Further research and continuous evaluation of cultivars are essential to ensure the sustainable growth and economic viability of spearmint farming.

Agro-practices

Soil and field preparation: Spearmint grows well in loamy to sandy loam soils that are rich in organic matter. It is highly sensitive to water-logging, so well-drained soil is essential to avoid root rot and related stress. The optimal soil pH range lies between 6.0-7.5, promotes nutrient availability and robust plant health. As for climate, spearmint prefers temperate to subtropical regions with moderate rainfall, ample sunlight, and cool nights conditions that support vigorous leaf growth and essential oil development. In warmer climates, some afternoon shade helps prevent overheating and leaf scorching. So, in summer choose a site with fertile, loamy or sandy-loam soil enriched organically, ensure excellent drainage, maintain soil pH between 6.0-7.5, and provide full to partial sun.

Field preparation: Begin by conducting primary tillage through deep ploughing to a depth of 25-30 cm, using a moldboard plough or equivalent implement to break hard clods, improve aeration, incorporate residues, and disrupt soil-borne pests and weeds. After ploughing, leave the field exposed to sunlight for about 7-10 days, which helps naturally reduce pathogens and pests by solarization of soil. Once primary tillage is complete and the soil is partially weathered, proceed with secondary tillage by making two to three crosswise passes using a disc harrow or cultivator.

Planting and Propagation: Spearmint is primarily propagated using shoots/runners between December and January. Approximately 4-5 quintals of stolons or runners are needed to plant in one hectare. After nursery raising, transplanting of plant should be done

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in February-March in main field. Late planting can lead to lower yields. Plant stolons in shallow furrows (7-10 cm deep) at a spacing of 45x30 cm gives better crop and higher oil yield. After planting, cover the furrows and provide light irrigation.

Improved varieties: The following table presents carvone, limonene & oil yield percentages for Spearmint improved varieties developed by CIMAP.

Cultivar	Carvone (%)	Limonene (%)	Oil yield (kg ha^{-1})
CIM-Mohak	56-58	18-23	50-55
MSS-5	55-59	20-22	55-60
Arka	64.35	19-20	50-55
Neera	50-51	20-23	40-45

Irrigation: Spearmint requires consistent moisture. Irrigate every 10-15 days in winter and in warm, dry climates or during peak summer heat irrigate every 7-10 days in summer.

Nutrient management: Apply well- decomposed FYM (Farm Yard Manure) or compost at the rate of 15-20 tons per hectare during final harrowing (field preparation). Inorganic Fertilizers: Apply for two cutting NPK- 150:60:40 and for one cuttings apply NPK- 80:40:40 per hectare. Apply the entire quantity of phosphorus and potassium, along with a portion of 1/3 nitrogen, as a basal dose during planting. Apply the remaining nitrogen in 2-3 splits during the growing season.

Major Insect & Pests

Aphids (*Myzus persicae*): Suck sap from leaves and stems, excrete honeydew causing fungal growth and reduces leaf surface and photosynthesis.

Control Measure: Apply Neem oil 2-3% or NSKE 5% spray acts as repellent and growth regulator or Neem cake 250-500 kg ha^{-1} at planting reduces soil-borne pest and aphid attack.

Cutworms (*Agrotis spp.*): Caterpillar larvae that survive on young stems at the soil line and feed at night and hide in soil during the day.

Control Measure: Deep ploughing, light traps and apply Neem oil/NSKE (Neem Seed Kernel Extract) 5% spray can repel moths and early instar larve.

Hairy caterpillar (*Diacrisia obliqua*): Feeds on the underside leaves of spearmint.

Control Measure: Hand picking and destruction of egg masses and young gregarious larvae in early stage, deep summer ploughing to expose and kill pupae and apply Neem oil 2-3% or NSKE 5% spray acts as repellent and growth regulator or application of neem cake 250-300 kg ha^{-1} improves soil health and reduces pest incidence.

Mint Leaf Roller (*Syngamia abruptalis*): Rolls leaves with silk and feeds inside.

Control Measure: Light traps, timely harvesting and apply neem based sprays at 7-10 days intervals during early stage infestation are effective.

Major Diseases of Spearmint

Rust (*Puccinia menthae*): Orange to reddish-brown pustules on underside of leaves and leaf drop.

Powdery Mildew (*Erysiphe cichoracearum*): White powdery fungal growth on leaf surfaces.

Control measures in Spearmint

Cultural Practice	Biological Controls
Use disease-free planting material Ensure well-drained soils to avoid root diseases Follow crop rotation (avoid repeated mint cropping) Remove and destroy infected plants	Use *Trichoderma harzianum* or *Pseudomonas fluorescens* for soil-borne pathogens Apply neem cake in nursery/fields to suppress fungal growth.

Harvesting and post-harvest management

Harvesting: Harvest spearmint when early flowering 30-50% flowering (flower pale purple) is considered the optimum harvest stage, typically in the summer for winter-planted crops. The first harvest should be taken 100-120 days after planting, with subsequent harvests at 45-60 day intervals. Cut plants 10cm above the ground on bright, sunny days using a sickle. Avoid harvesting on cloudy or rainy days.

Post-Harvest management: Allow the harvested herb to wilt in the shade for a one or two days before distillation. Spearmint oil is extracted mainly by steam distillation (2-3 hours per batch) of fresh or partly wilted aerial parts of the plant (leaves and stems).

Oil storage: Optimum aroma, carvone content and shelf life are important aspect of industrial quality spearmint essential oil. It is recommended to keep the oil in airtight container such as amber-colored glass bottles or food-grade stainless steel drums, as these materials prevent reactions with the oil components. The container should be kept in cool, dry place at a temperature of around 15-20˚C, away from direct sunlight and sources of heat.

Yield and profitability

Under subtropical conditions, in one cutting of spearmint essential oil yields of 55-60 kg ha^{-1} with good management practice, whereas in two cuttings reported oil yields is 80-85 kg ha^{-1}. Current Indian market prices range from Rs. 2500 kg^{-1} (depending on quality and industrial demand).

Quality planting material production of spearmint

Conclusion

Spearmint cultivation presents a viable and profitable opportunity to enhance the socio-economic conditions of farmers, particularly small and marginal landholders. Its high market demand, short growing period, and adaptability to various agro-climatic regions make it a promising crop for income generation. With the adoption of modern agricultural practices and strong market linkages, farmers can earn substantial returns with minimal investment. When supported by government initiatives, farmer training, and cooperative networks, spearmint farming can drive rural development, uplift farming communities, and promote sustainable livelihoods.

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Community Seed Banks and Local Varietal Conservation

Harini S., Harinbalan R., Harish V. and Punitha S. P.

Abstract

Agricultural biodiversity underpins food security, ecosystem stability, and sustainable farming practices. Yet, it is increasingly at risk due to monocropping, industrialized agriculture, and climate change. Community Seed Banks (CSBs) have emerged as farmer-led, grassroots initiatives dedicated to conserving, regenerating, and distributing traditional crop varieties. By safeguarding genetic diversity, they strengthen seed sovereignty and climate resilience. This paper examines the contribution of CSBs to local varietal conservation, emphasizing their role in seed collection, storage, regeneration, and exchange. It also highlights their cultural, ecological, and socio-economic benefits. Drawing on surveys, interviews, focus group discussions, and field observations, the study analyzes operational models, varietal documentation, and the impacts of CSBs. Case studies from India, Nepal, and Peru demonstrate their effectiveness in conserving indigenous crops while empowering communities. Despite these successes, challenges such as policy restrictions, weak infrastructure, and declining traditional knowledge remain. Strengthening CSBs through supportive policy frameworks, technical aid, and community participation is essential to sustain agrobiodiversity and build resilient food systems.

Introduction

Seeds form the backbone of agriculture and are central to food and nutrition security. However, globalization, climate variability, and the dominance of high-yielding uniform varieties have led to the erosion of traditional landraces. Community Seed Banks (CSBs) serve as grassroots strategies to counter this trend by conserving, restoring, and promoting the use of local crop varieties. They are farmer-managed repositories that ensure biodiversity, preserve cultural knowledge, and secure seed sovereignty. Over the past century, the expansion of industrial farming, monocultures, and dependency on hybrid seeds has reduced global crop diversity. According to FAO, nearly 75% of plant genetic diversity has been lost as farmers have shifted from traditional landraces to genetically uniform cultivars. CSBs, by contrast, act as repositories of indigenous seeds adapted to local agro-ecological conditions, thus contributing to both resilience and cultural preservation. Examples such as Navdanya in India and participatory seed bank models in Nepal illustrate their success. Nevertheless, CSBs face challenges, including limited infrastructure, inadequ-

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ate policies, and the erosion of traditional knowledge. This study explores their roles in varietal conservation, farmer empowerment, and policy integration.

Community Seed Banks

A Community Seed Bank is a farmer-driven system for collecting, storing, regenerating, and sharing locally adapted crop varieties. Unlike centralized gene banks, CSBs remain embedded within farming communities and operate through:

Seed Collection and Documentation: Identifying and recording traits of local varieties.

Seed Storage and Maintenance: Ensuring viability with locally adapted methods.

Seed Exchange and Lending: Distributing seeds to members with a return model.

Capacity Building: Training farmers in selection, storage, and sustainable practices.

Importance of CSBs

Community seed banks provide multiple benefits:

Biodiversity Preservation: Safeguarding crop genetic diversity.

Climate Resilience: Maintaining varieties tolerant to stresses such as drought or pests.

Seed Sovereignty: Reducing reliance on commercial seed markets.

Cultural and Nutritional Value: Retaining heritage crops rich in nutrition and cultural importance.

Functions of CSBs

- ✓ Collecting and recording traits of local cultivars.
- ✓ Storing seeds using traditional or modern methods.
- ✓ Regenerating seeds through regular cultivation cycles.
- ✓ Facilitating seed exchanges within communities.
- ✓ Building farmer knowledge and capacity in seed conservation.

Case Studies

Navdanya, India: Conserves 4,000+ rice varieties and operates over 120 seed banks.

Maramche, Nepal: Maintains 12 local crops, including high-altitude rice.

Beej Bachao Andolan, Uttarakhand: Preserves 400 traditional varieties through mixed cropping.

Potato Park, Peru: Protects hundreds of indigenous potato varieties with community collaboration.

Challenges

- ✓ Limited storage infrastructure and financial resources.
- ✓ Decline in traditional seed knowledge.
- ✓ Restrictive seed laws and weak policy support.
- ✓ Sustaining community participation over time.
- ✓ Policy and Institutional Support

Strengthening CSBs requires

- ✓ Integration into national biodiversity strategies.
- ✓ Technical and financial support from governments and NGOs.
- ✓ Networking and regional seed exchange systems.
- ✓ Educational programs to transfer traditional knowledge.

Conclusion

Community Seed Banks are not just seed repositories but living institutions that conserve biodiversity, strengthen farmer autonomy and prese-

rve cultural identity. They provide resilience against climate shocks while ensuring seed sovereignty. Supportive policies, technical innovat-ions and participatory governance are crucial to sustain their role in food security and biodiversity conservation.

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Agrivoltaics: Powering Agriculture with Solar Innovation

Ayushman Srivastava

For centuries, farming has depended on sunlight as the primary energy source for crop growth. Today, technology has opened a new frontier that enables farmers to harvest sunlight twice once for food production and again for clean electricity. This groundbreaking concept is called agrivoltaics, and it is emerging as one of the most promising innovations in sustainable agriculture.

What is Agrivoltaics?

Agrivoltaics is the integration of solar photovoltaic systems with agriculture on the same land. Instead of competing for land between food and energy, this system allows solar panels to be installed above or alongside crops, creating a dual-use model. Farmers can continue cultivating while also generating renewable electricity from the same field.

How does it Work?

Solar panels are strategically installed at a raised height, allowing sufficient sunlight to reach the plants. The panels not only provide shade to crops, protecting them from extreme heat, but also generate power simultaneously. Interestingly, the crops below help cool the panels by reducing ambient temperature, which enhances the panels' efficiency. This synergy creates a win-win situation for both food and energy production.

Key Benefits of Agrivoltaics

Land Productivity: Farmers gain both crop yield and electricity without sacrificing farmland.

Climate Resilience: Shade reduces crop stress and evaporation, conserving water in drought-prone areas.

Sustainable Energy: Renewable electricity can power irrigation systems, cold storage, or be sold to the grid.

Income Diversification: Energy generation ensures farmers a steady income beyond seasonal harvests.

Environmental Benefits: Reduces carbon footprint and supports the shift toward clean energy.

Global and Indian Examples

- ✓ In India, agrivoltaics is gaining traction in states like Maharashtra and Gujarat, where farmers

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grow vegetables under solar panels while selling surplus electricity

- ✓ In France and Japan, agrivoltaic farms produce tea, grapes, and tomatoes successfully.
- ✓ In the U.S., pilot projects demonstrate how solar farms with cattle grazing can be highly productive and sustainable.

Challenges and Way Forward

Agrivoltaics is not without challenges. High installation costs, lack of technical know-how, and the need to adapt farming equipment remain hurdles. However, with government incentives, research support, and private investment, agrivoltaics could become a mainstream farming practice. In the future, solar-powered farms may become a common landscape, addressing both food security and energy demand simultaneously.

Conclusion

Agrivoltaics represents a paradigm shift in agriculture turning farms into dual powerhouses of food and energy. With rising climate challenges and limited land resources, innovations like agrivoltaics are not just desirable but essential for a sustainable future.

Biostimulants in Sustainable Horticulture: Unlocking the Potential of Fruit Crop

Tanvi Rana, Rewa Dhiman and Sanjeev Kumar

Introduction

The human population worldwide is predicted to grow 9.1 billion in the next three decades about 34% higher than today. In order to keep up with the growing population, this will increase the demand for food. Chemical fertilizers have long been a major factor in raising food output, but they also degrade soil health and food quality (Sharma *et al.*, 2022). Many novel solutions have emerged in recent years to increase the sustainability of horticulture crop production. The use of natural plant biostimulants has become more significant over the past ten years, and biostimulants may provide a new idea to address this difficulty and raise output to the optimal level. Natural compounds or microbes known as biostimulants help plants grow, absorb nutrients, and become more tolerant to stress without the need for fertilizers or other nutrient supplies. Fruit crops can benefit greatly from the use of biostimulants since they are essential for improving both structural and functional plant traits which eventually improve quality as well as overall yield of fruit crops (Fig. 1). Applying biostimulants also aids in increasing physiological processes like as photosynthesis, protein and carbohydrate content, enzyme activity, nutrition metabolism, and chlorophyll (Sharma *et al.*, 2021). Enhancements in antioxidant activity, redox balance, stress responsiveness cascades, and hormonal homeostasis caused by biostimulants ameliorate abiotic stressors such as salt, water, temperature and humidity extremes.

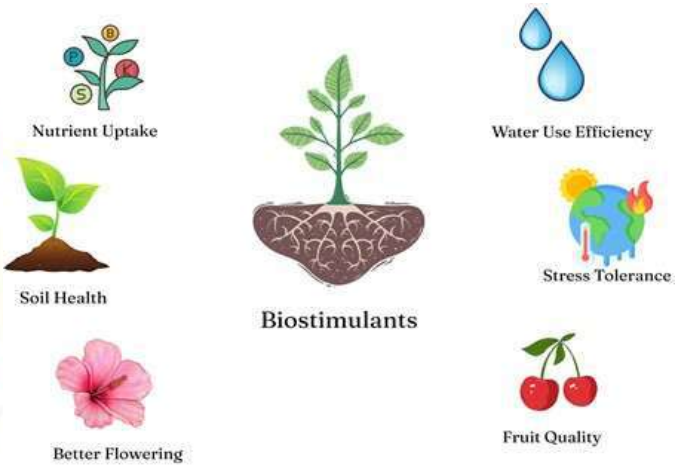

Fig. 1. Utilization of biotimulants in fruit crop production

Classification of biostimulants

In the fruit industry specifically, bostimulants have emerged as attractive tools for sustainable agriculture. The use of well-known substances like humic substances, protein hydrolysates, phosphites, beneficial microbes, and chitosan has been shown for enhancing growth, absorption of nutrients, fruit

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quality and resilience to stress without the negative side effects of chemical fertilizers.

Humic substances: Humic compounds are a naturally occurring portion of soil organic matter that are produced by microbial, animal, and plant decomposition. It comprises fatty acids, steroid compounds, poly-methylene chains, and the humus fraction which is soluble in aqueous alkaline solutions but precipitates at acidic pH levels combine to form humic acids. In winter guava plantings, bio-inoculants combined with humic acid enhanced vegetative and blooming attributes as well as fruit output, soil quality, and leaf nutritional content (Narasimhaiah *et al*., 2022).

Seaweed extracts and botanicals: Seaweed based biostimulants are derived from red, green and brown marine algae rich in phytohormones. The foliar application of seaweed extract at pre flowering and fruit set stage in strawberry enhanced the flowering traits, cummulative yield, runner production and fruit quality attributes. Similarly, foliar applications of an extract (*Ascophyllum nodosum*) on grape vines increased their anthocyanin and phenolic concentrations at the time of harvest.

Protein hydrolysates: This category of biostimulants comprises amino acids and peptides (oligopeptides and polypeptides) produced through partial hydrolysis. It enhances the rhizosphere zone's microbial and enzymatic activity. The root as well as foliar application of protein hydrolysates in Banana increased the chlorophyll content in leaves and increase the root and shoot biomass in Guava through foliar application.

Chitosan: It is a naturally occurring biopolymer that is derived from natural components such as fungal cell walls, insect exoskeletons, and crustacean shells. The physiological action of chitosan polymers in plants includes binding to particular receptors as well as binding to cell surface components and DNA. The foliar application of Chitosan @ 12, 250, 500 and 1000 ppm at pre flowering and 10% flowering stage in Strawberry cv. Festival resulted in maximum synthesis of carotenoids, flavonoids and phenolic compounds with higher antioxidant activities (Koly *et al.*, 2024)

Microbial biostimulants

Arbuscular mycorrhizal fungi (AM Fungi): Arbuscular mycorrhiza fungi are obligatory biotrophic soil borne fungus that absorb plant photosynthetic products like sucrose. By producing phosphatases from organic phosphorus compounds, AM fungus can provide crops with an abundant source of nutrients. Additionally, it increases the extra radical hyphae by promoting the uptake of nitrogen, mineral cations (K^+, Ca^{2+}, $Mg^{2+,}$ and Fe^{3+}) and micronutrients like Cu and Zn (immobile). In Strawberry, mycorrhizal species like *Funneliformis mosseae and Funneliformis geosporus* enhance plant performance under drought stress (Singh *et al*., 2024).

Bacteria: Microorganisms in the soil can play a vital part in controlling the dynamics of nutrients and the breakdown of organic materials. There are two primary types of bacteria used as biostimulants in

agricultural production systems:

- ✓ Rhizobium
- ✓ Plant growth promoting rhizobacteria

Benefits of Sustainable Agriculture and Ecological Impacts: The transition from synthetic chemicals to biostimulants promotes sustainable agriculture due to their reduced environmental impact. Factors contributing to soil health improvement include reduced need for chemical fertilizers and improved crop resistance to climate change (Rana *et al.*, 2022). Biostimulants reduce chemical reliance and prevent toxic materials from leaching into rivers and groundwater to preserve biodiversity in orchards.

Challenges and Future Prospectus

Despite their potential, there are still certain challenges to overcome before biostimulants can be used in fruit crops which include research-based field trials, recommendations suited to individual crops and lack of knowledge among marginal and small farms.

Biostimulants have a lot of promise for integrated fruit production systems in the future. They can be used in conjunction with climate-smart agriculture, organic production, and precision farming to create a more vigorous and resilient fruit industry.

Conclusion

Based on the above discussions, it can be stated that biostimulants are a unique form of technology that can be used to improve traditional farming methods. In real terms, biostimulants have been effectively employed for a number of reasons such as improving crop quality and production as well as boosting resistance to salinity, water stress, low and high temperatures. Their combination with organic systems, precision farming and environmentally friendly techniques may render fruit production a sustainable paradigm.

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Climate Change and Its Impact on Soil and Water Resources

M. K. Meena, R. K. Patel, Deepak Singh and Dinesh Kumar

Introduction

Climate change, defined as the long-term alteration of temperature, precipitation, wind patterns, and other elements of the Earth's climate system, is a central environmental issue of our time. Driven predominantly by anthropogenic activities such as fossil fuel combustion, deforestation, and industrial agriculture, climate change is reshaping ecosystems and natural processes at global and regional scales. Among the most critically affected natural resources are soil and water, which form the foundation of terrestrial life, agriculture, and ecological sustainability. This chapter aims to provide a detailed exploration of how climate change is influencing soil and water systems, backed by data, scientific analysis, and practical frameworks for mitigation and adaptation. The target audience includes graduate students, researchers, and practitioners in environmental science, agriculture, and water resource management.

Understanding climate change: The Earth's climate system is driven by interactions between five major components: the atmosphere, hydrosphere, cryosphere, lithosphere, and biosphere. Each of these subsystems interacts through complex feedback loops and energy exchanges that influence global climate patterns. Climate change is primarily driven by the enhanced greenhouse effect, where human-induced emissions of greenhouse gases (GHGs) trap infrared radiation in the atmosphere, leading to increased global temperatures.

Greenhouse gases and their roles

Carbon dioxide (CO_2): The most significant anthropogenic GHG, largely emitted through fossil fuel combustion, deforestation, and land-use changes.

Methane (CH_4): Emitted from agriculture (especially rice paddies and livestock), landfills, and fossil fuel extraction.

Nitrous oxide (N_2O): Arises from fertilizer application and certain industrial processes.

These gases differ in their Global Warming Potential (GWP), with methane being 25 times and nitrous oxide 298 times more potent than carbon dioxide over a 100-year period. Once released, GHGs remain in the atmosphere for decades to centuries, intensifying radiative forcing the difference between solar energy absorbed by the Earth and energy radiated back to space.

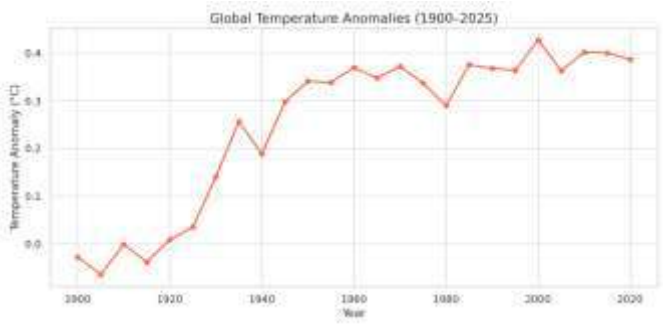

Fig 1: Global average temperature rise (1880-2020)

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Table 1: Climate Change Drivers and their impacts on soil health and functionality

Climate driver	Soil impact mechanism	Environmental & agronomic consequence	Reference
Rising temperatures	Increases microbial respiration and speeds up organic matter breakdown	Decline in soil organic carbon (SOC), reduced fertility	Lal, 2004; IPCC, 2019
Intense rainfall	Enhances surface runoff, promotes detachment of particles and leaching	Loss of topsoil, nutrient depletion, decreased arable land	Nearing *et al.*, 2004; Panagos *et al.*, 2015
Prolonged droughts	Depletes soil moisture, hardens structure, impedes biological activity	Reduced infiltration, compaction, inhibited root growth	Schimel *et al.*, 2007; FAO, 2015
Sea-level rise	Facilitates saltwater intrusion in coastal soils	Salinization, loss of agricultural productivity	Nicholls & Cazenave, 2010; Wong *et al.*, 2014 (IPCC)

Table 2: Impact on water resources

Impact area	Climate change effect	Implications
Precipitation	Unpredictable rainfall, changing patterns	Water scarcity or flooding
Surface water	Increased evaporation from reservoirs	Lower storage and irrigation supply
Groundwater	Reduced recharge in dry spells	Over-extraction, declining water tables
Water quality	Sediment and contaminant runoff	Unsafe drinking and irrigation water

Figure 1 illustrates the rise in global average surface temperatures from 1880 to 2020, showing a clear upward trend, especially since the 1970s. While natural fluctuations are present due to volcanic activity and ocean-atmosphere cycles (e.g., *El Niño*), the overall pattern reflects a sustained increase of approximately 1.1°C above pre-industrial levels, largely attributed to anthropogenic greenhouse gas emissions. This warming trend correlates strongly with the industrial era's rise in CO_2 concentrations and highlights the accelerating pace of climate change. The figure underscores the urgency of limiting further warming to meet the targets set by the Paris Agreement and avoid crossing critical climate thresholds.

Impact on Soil resources

Soil is a dynamic and living natural system that underpins terrestrial ecosystems, agricultural productivity, and global carbon cycling. It plays crucial roles in nutrient provisioning, water filtration, climate regulation and biodiversity support. However, climate change is exerting significant pressure on soil functions through a range of interlinked stressors, ultimately affecting land productivity, ecosystem stability, and food security. Recent studies estimate that nearly 33% of global soils are already degraded, and climate change is accelerating this trend (FAO, 2020). Soil erosion alone may cause the loss of 25 to 40 billion tonnes of topsoil globally each year, threatening food security for over 3.2 billion people (UNCCD, 2017).

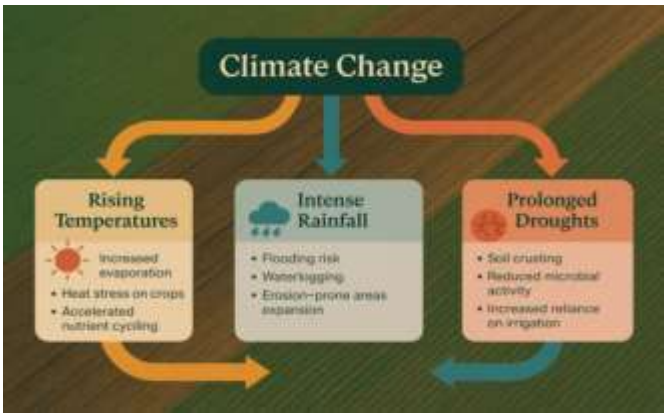

Fig 2: A graphical illustration of impact of climate change

These impacts collectively reduce soil resilience, compromise food security and amplify land degradation processes such as erosion, compaction, salinization, and desertification.

Soil structure, porosity, and biological diversity are also disrupted, leading to lower water infiltration, poor root development, and increased vulnerability to pests and diseases.

Fig. 3: Impact of climate change on water resources

Conclusion

Climate change is strongly affecting the Earth's natural systems, with soil and water being the most at risk. Higher temperatures, unpredictable rainfall, long droughts, and rising sea levels are damaging soils through erosion, loss of nutrients, and increased salinity. This puts farming and ecosystems in danger, reducing food security for millions of people. Since greenhouse gases stay in the atmosphere for a long time and their impacts are growing, it is urgent to take action. Protecting soil and water is key to protecting nature, supporting human life, and achieving global climate goals.

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Concepts of Cn-Resistant Respiration - Alternative and Sham-Sensitive Electron Transport Chain in Plants

Arthi V., S. Nadarajan, Arthy R. and Teresa Mary Agastian

Abstract

Plants exhibit a unique mitochondrial respiration mechanism that includes an alternative oxidase (AOX) pathway, which functions as a bypass to the conventional cytochrome electron transport chain (Vanlerberghe and McIntosh, 1997). This alternative pathway is resistant to cyanide (CN), a known inhibitor of Complex IV (cytochrome c oxidase) in the classical electron transport chain (Møller, 2001). Unlike the cytochrome pathway, AOX-mediated respiration is sensitive to salicylhydroxamic acid (SHAM), a compound that specifically inhibits AOX activity by targeting its di-iron active site (Umbach and Siedow, 1993). The AOX pathway transfers electrons from the ubiquinol pool directly to molecular oxygen, thereby bypassing both Complex III and Complex IV of the mitochondrial electron transport chain (Rasmusson *et al*., 2004). Experimental studies involving CN and SHAM have provided valuable tools to discriminate between the two respiratory pathways and have helped quantify AOX's contribution to overall plant respiration (Ribas-Carbo *et al*., 2005). Thus, understanding the structure, regulation, and functional significance of the AOX pathway is crucial for improving plant productivity and stress adaptation through metabolic engineering (Vanlerberghe, 2013).

Introduction

Plant respiration is a fundamental process that generates ATP and supports biosynthetic and maintenance functions (Millar *et al*., 2011). While most eukaryotes rely exclusively on the cytochrome pathway for oxidative phosphorylation, plants possess an additional alternative electron transport route mediated by AOX (Vanlerberghe and McIntosh, 1997). This alternative pathway is cyanide-resistant, meaning it remains functional even in the presence of CN, which inhibits Complex IV of the cytochrome pathway (Møller, 2001). The pathway is, however, inhibited by SHAM, a specific inhibitor of AOX, which makes it a useful tool in dissecting mitochondrial respiration (Umbach and Siedow, 1993).

Overview of Mitochondrial Electron Transport

In plants, the electron transport chain (ETC) is composed of multiple complexes Complex I (NADH: ubiquinone oxidoreductase), Complex II (succinate dehydrogenase), Complex III (cytochrome bc_1 complex), and Complex IV (cytochrome c oxidase) (Møller, 2001). Electrons enter the ETC from NADH at Complex I and from $FADH_2$ at Com-

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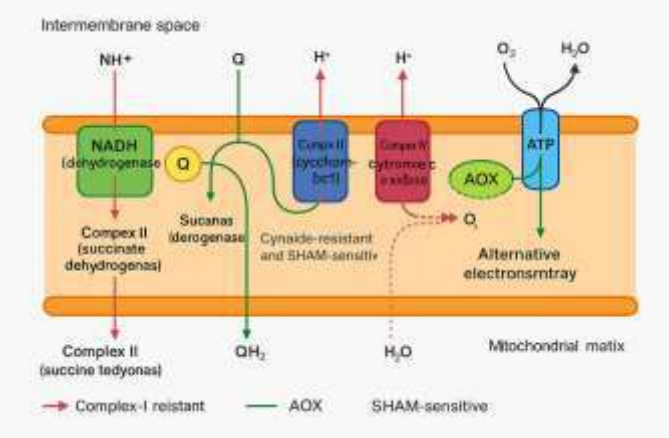
plex II, and are passed to ubiquinone (coenzyme Q), which becomes ubiquinol upon reduction (Rasmusson *et al*., 2004). Ubiquinol then transfers electrons to Complex III, which relays them via cytochrome c to Complex IV, where oxygen is reduced to water (Millar *et al*., 2011). As electrons move through these complexes, protons are pumped from the matrix into the intermembrane space, creating an electrochemical gradient or PMF (Rasmusson *et al*., 200)]. This proton gradient is utilized by Complex V (ATP synthase) to drive the synthesis of ATP from ADP and inorganic phosphate (Pi) (Millar *et al*., 2011).

A unique feature of plant mitochondria is the presence of alternative respiratory components that allow electrons to bypass parts of the classical ETC (Vanlerberghe and McIntosh, 1997). The most prominent among these is the alternative oxidase (AOX), which provides a cyanide-resistant, SHAM-sensitive route for electrons to flow from ubiquinol directly to oxygen without contributing to the proton gradient (Umbach and Siedow, 1993). This non-phosphorylating branch of the ETC is considered less efficient in ATP production but plays crucial roles in ROS management, metabolic flexibility, and stress adaptation (Maxwell *et al.*, 1999). Plant mitochondria also contain other bypass components such as type II NAD(P)H dehydrogenases and uncoupling proteins (UCPs) that modulate energy balance and redox state (Rasmusson *et al*., 2008).

- ✓ Complex I (NADH dehydrogenase)
- ✓ Complex II (Succinate dehydrogenase)
- ✓ Ubiquinone (Q) and Ubiquinol (QH_2)
- ✓ Complex III (Cytochrome bc_1 complex)
- ✓ Cytochrome c
- ✓ Complex IV (Cytochrome c oxidase)
- ✓ AOX (Alternative Oxidase)
- ✓ ATP synthase (Complex V)
- ✓ Oxygen (O_2) as the terminal electron acceptor
- ✓ Proton pumping sites and ATP production
- ✓ Arrows showing electron flow and proton translocation

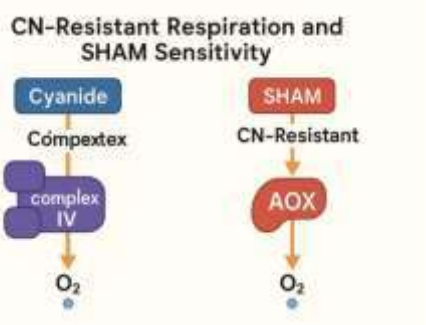
The AOX pathway bypasses Complexes III and IV, transferring electrons from QH_2 directly to oxygen without proton pumping or ATP production.



CN-Resistant Respiration and AOX Pathway

The cytochrome pathway, which includes Complex IV (cytochrome c oxidase), is the terminal component of the classical mitochondrial electron transport chain and is highly sensitive to cyanide (CN) (Møller, 2001). Cyanide binds irreversibly to the heme a_3-CuB center of Complex IV, blocking electron transfer to oxygen and thereby halting ATP synthesis (Millar *et al.*, 2011). However, many plants exhibit a cyanide-resistant respiratory activity, which is mediated by alternative oxidase (AOX), allowing

respiration to continue even in the presence of CN (Vanlerberghe and& McIntosh, 1997). This alternative pathway bypasses both Complex III and Complex IV, transferring electrons from reduced ubiquinol (QH_2) directly to oxygen via AOX (Rasmusson *et al.*, 2004). While AOX is resistant to cyanide, it is sensitive to salicylhydroxamic acid (SHAM), a hydroxamic acid derivative that binds to the diiron center of the AOX enzyme and inhibits its activity (Umbach and Siedow, 1993). SHAM inhibition is commonly used in respiration assays to selectively block AOX activity and quantify the contributions of each pathway to total respiration (Ribas-Carbo *et al.*, 2005). Thus, the use of CN and SHAM in combination allows researchers to distinguish between the cytochrome and alternative pathways (Saika *et al*., 2002). This has been demonstrated in several plant species such as Arabidopsis thaliana, Nicotiana tabacum, and Oryza sativa, where AOX activity was shown to sustain respiration under CN exposure but was suppressed by SHAM (Yoshida *et al*., 2007).



Physiological Roles of the Alternative Pathway

Redox Balance and Reactive Oxygen Species (ROS) Control: AOX helps maintain the redox poise of the mitochondrial ETC. Under stress conditions (e.g., drought, high light, salinity, pathogen attack), excess NADH and over-reduction of the ETC can lead to ROS generation. AOX reduces ROS formation by allowing continued electron flow and minimizing over-reduction of ETC components.

Energy Overflow and Metabolic Flexibility: AOX pathway is a non-phosphorylating route (does not produce ATP). It allows continued carbon metabolism (glycolysis, TCA cycle) even when ATP demand is low or oxidative phosphorylation is impaired. This prevents feedback inhibition on upstream metabolic processes.

Stress Tolerance and Adaptation: AOX expression is induced under abiotic (e.g., cold, drought) and biotic stress (e.g., pathogen infection). By mitigating oxidative damage and maintaining metabolic flux, AOX supports plant survival under stress.

Thermogenesis (in Some Plants): In thermogenic plants (e.g., Arum, Philodendron), AOX activity generates heat. This helps volatilize odorants to attract pollinators**.**

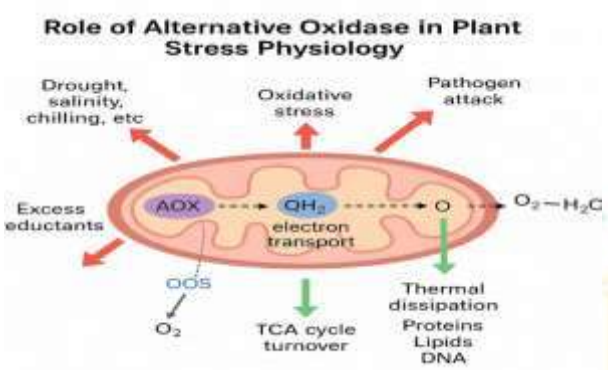
Photorespiration and Photosynthesis Modulation : During high light or drought, photorespiration increases, leading to higher NADH production in mitochondria. AOX allows mitochondria to reoxidize NADH, maintaining the operation of photorespiration and preventing photoinhibition**.**

Developmental Regulation: AOX is involved in seed germination, pollen development, fruit ripening, and senescence. It contributes to energy balance and redox control during high metabolic

activity phases.

Interplay with Primary Respiration: AOX provides an "overflow" valve when the cytochrome pathway is saturated or impaired. It ensures electron flow continuity, maintaining cellular homeostasis.

Programmed Cell Death: AOX helps modulate ROS signaling, affecting the balance between cell survival and death during stress-induced PCD (Robson and Vanlerberghe, 2002).



Regulation of AOX Expression and Activity

The expression and activity of alternative oxidase (AOX) in plants are tightly regulated at both transcriptional and post-translational levels to meet varying physiological and environmental demands (Vanlerberghe and McIntosh, 1997).

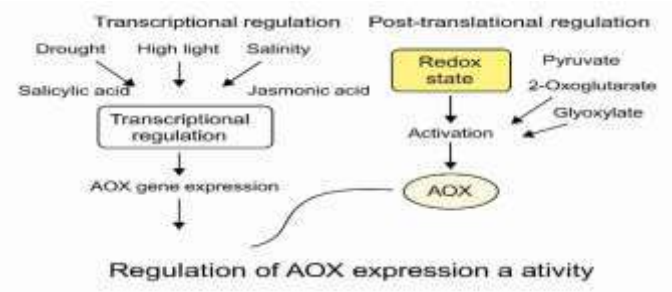
Transcriptional Regulation: AOX is encoded by a small multigene family in most plant species, and its expression is tissue-specific, developmentally regulated and inducible under various stress conditions (Saisho *et al*., 2001). Stress signals such as drought, high light, salinity, cold, and pathogen attack often lead to upregulation of AOX transcripts through activation of stress-responsive promoters (Clifton *et a*l., 2006). Phytohormones like salicylic acid (SA), jasmonic acid (JA), and abscisic acid (ABA) act as important signaling molecules that trigger AOX expression in response to both biotic and abiotic stress (Van Aken *et al*., 2009). For example, exogenous application of SA leads to the rapid induction of AOX1a in Arabidopsis, linking it to plant immune responses (Zhang *et al*., 2012). Additionally, AOX gene expression is regulated by retrograde signaling, where changes in mitochondrial function are sensed by the nucleus, triggering compensatory transcriptional responses (Van Aken *et a*l., 2009). This allows plants to coordinate mitochondrial and nuclear gene expression, ensuring efficient stress responses and energy regulation.

Post-Translational Regulation: Even after transcription, AOX activity is finely tuned through post-translational modifications (PTMs) and metabolite-based regulation (Umbach *et al*., 2006). The AOX protein exists in two forms: an inactive oxidized dimer and an active reduced monomer, controlled by disulfide bond formation between conserved cysteine residues (Umbach and Siedow, 1993). Reductive activation occurs in response to changes in cellular redox state, particularly via thioredoxins or glutaredoxins, which reduce AOX and render it catalytically active (Ribas-Carbo *et* al., 2005).

The activity of AOX is also regulated allosterically by metabolites such as pyruvate, 2-oxoglutarate, and glyoxylate, which bind and activate AOX by increasing its electron transfer capacity (Millar *et al*., 2011). Among these, pyruvate is considered the most potent natural activator and

plays a crucial role in regulating AOX flux during periods of high carbon flow through glycolysis (Vanlerberghe, 2013). Environmental stress and metabolic imbalances, such as low ATP demand, over-reduction of ubiquinone pool, or ROS buildup, also act as triggers to activate AOX, either by modifying redox status or by enhancing metabolite signals (Clifton *et al*., 2006).

Functional Implications of AOX Regulation: The precise control of AOX ensures that it is activated only when needed, thus preventing unnecessary energy loss while protecting cells from oxidative damage (Maxwell *et al*., 1999). This dynamic regulation allows AOX to act as a buffer system, supporting metabolic flexibility and cell survival under stress without compromising energy efficiency under normal conditions (Vanlerberghe, 2013). Transcriptional regulation: AOX gene expression increases under stress, in part via signaling molecules like ROS and nitric oxide (Van Aken *et al.*, 2009). Post-translational regulation: AOX activity is modulated by pyruvate and α-keto acids, which activate it by binding to its regulatory cysteine (Millar *et al*., 2011). Environmental cues such as pathogen infection, temperature shifts, nutrient availability influence AOX expression (Saisho *et al.*, 2001).



Regulation of AOX expression a ativity

Experimental Evidence and Inhibitor Studies

CN and SHAM are used to differentiate between the classical and alternative pathways (Day *et al*., 1996). Respiration measured in presence of CN (cytochrome pathway blocked) and SHAM (AOX blocked) helps quantify pathway activity (Ribas-Carbo *et al*., 2005).

Implications for Agriculture and Biotechnology

Over expression of AOX has been used to enhance tolerance in crops like tomato, Arabidopsis, and rice (Saika *et al*., 2002). AOX modulates ROS levels, protecting photosynthetic machinery under stress (Yoshida *et al*., 2007).

Conclusion

The alternative oxidase (AOX) pathway represents a unique and highly adaptive feature of plant mitochondrial respiration, offering metabolic flexibility and protection against oxidative stress. Unlike the cytochrome pathway, AOX is cyanide-resistant and SHAM-sensitive, providing an essential bypass that maintains electron flow and redox balance even when the classical pathway is compromised (Vanlerberghe and McIntosh, 1997). Although it is non-phosphorylating and does not directly contribute to ATP synthesis, its protective role in metabolism and cellular redox regulation is essential under conditions of energy excess or oxidative load (Vanlerberghe, 2013). The regulation of AOX is multifaceted, involving both transcript-ional responses to environmental and hormonal signals and post-translational modifications that control its enzymatic activity (Umbach *et al.*, 2006).

In light of increasing climate variability and environmental stress, AOX has emerged as a promising molecular target for the development of stress-resilient crops. Genetic engineering to modulate AOX expression has shown positive impacts on plant survival, growth, and yield stability under abiotic and biotic stress (Yoshida *et al*., 2007; Saika *et al*., 2002). Future research should focus on integrating AOX with other stress response networks, unraveling its cross-talk with chloroplast function, hormonal regulation, and programmed cell death pathways, and leveraging it in crop improvement programs. In conclusion, AOX is more than just an alternate respiratory enzyme it is a central player in plant stress tolerance, redox homeostasis, and metabolic plasticity, highlighting its vital role in both basic plant biology and agricultural innovation.

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New Advances in Plant Disease Diagnostic Techniques for Early Disease Management

Bhavna Sharma, Devshree Panchbhai and Priya Satwadhar

Abstract

Plant pathogens, including viroids, viruses, bacteria, nematodes, phytoplasma, oomycetes, fungi, and other groups such as protozoa, algae, parasitic phanerogams, and arthropods, pose significant threats to global crop production. While asymptomatic plants can serve as sources of inoculum, early detection of pathogens is crucial for effective disease management. Traditional diagnostic methods, often limited by symptom-based observation, can be insufficient, particularly when pathogens remain undetected during the asymptomatic phase. Recent innovations in plant disease diagnostics, such as biosensors, high-throughput sequencing (NGS), remote sensing technologies, and CRISPR-based diagnostics, are transforming plant health management by offering faster, more precise, and scalable solutions. These advanced tools enable early detection, accurate identification, and continuous monitoring of plant diseases, enhancing agricultural practices and food security. The convergence of these technologies in human healthcare, such as machine learning/AI and microarray technologies, has inspired their application in plant disease management, promoting timely interventions and sustainable crop production. Although challenges remain in validation, data privacy, and regulation, these innovations promise to significantly improve disease detection, resource allocation, and global food security.

Introduction

The major plant pathogens causing losses worldwide are viroids, viruses, bacterial, nematodes, phytoplasma, oomycetes, and fungi. In addition, some other pathogenic groups are protozoa, algae, parasitic phanerogams and arthropods. Plant pathogens may induce symptoms in certain plant species or cultivars. Symptoms of infection caused by some pathogens may be visible only at a certain developmental or vegetative stage of the host plant. Fully asymptomatic plants usually do not show yield losses, but can serve as an inoculum source to spread the pathogen to other susceptible plants or crops. The infectivity process typically requires that the patho-

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gen reproduce and establish a parasitic relationship with a susceptible host plant. In view of this, a great number of operations are required to diagnose a poorly understood disease. Examination of typical symptoms by simple comparison can be insufficient or misleading for correct diagnosis if the symptoms are poorly understood or when performed by inexperienced observers. Thus, new innovative methods in plant disease diagnosis are needed to detect an associated pathogen still in the asymptomatic phase (Delgado *et al*. 2020). New-generation plant disease diagnostic tools, such as biosensors, high-throughput sequencing, and remote sensing technologies, are revolutionizing plant health management by offering faster, more accurate and scalable solutions compared to traditional methods. These advanced techniques enable early detection, precise identification and efficient monitoring of plant diseases, contributing to sustainable agricultural practices and improved food security.

Key advancements in plant disease diagnosis

Biosensors: Biosensors have appeared as advanced detection tools used in many research fields including environmental monitoring, detection of airborne pathogens, real-time detection of human blood components and pathogens and pesticide residues in foods and beverages (Liu *et al*., 2018). The nanostructure combined with biological recognition elements to provide pathogen, bio-molecule, or environmental signal detection with a high degree of sensitivity and specificity. It provides a quick, reversible, and non-destructive assay of target molecules straight from the sample. The nanomaterials used in sensors greatly enhance the system's sensitivity. The biological element that plays the role of a bioreceptor can be antibody, DNA, enzyme, tissue type, whole cell etc. These bioreceptors are responsible to provide recognition specificity to the biosensor through the selective nature of the biochemical interaction. Based on the transducer type, a biosensor may be classified as an electrochemical, optical, thermal, or piezoelectric biosensor (Sawant, 2017). Regiart *et al*. (2017) developed a microfluidic electrochemical immunosensor for the early detection of *Xanthomonas arboricola* in walnut plant samples. This *in-situ* diagnostic was three times faster than ELISA and provided significantly higher specificity and sensitivity.

High-throughput Sequencing (NGS): The ongoing development of high-throughput sequencing (HTS; also known as next-generation sequencing) technologies has resulted in a dramatic reduction in DNA sequencing costs, making the technology more accessible to the average. These biotechnology advances are increasingly being applied to the study of plant and animal infectious diseases, and they are beginning to revolutionize the way biological and evolutionary processes can be studied at the molecular level. HTS application in natural and none cultivated crop communities has been significantly explored to determine viral diversity, new variants, emerging future threat species, and identification of unknown hosts of known viruses. NGS allows for

comprehensive pathogen profiling, including the identification of multiple viruses simultaneously and the detection of novel strains, which is crucial for understanding and managing plant diseases. NGS shows high resolution regarding the bacterial genotypes and is a significant and powerful method in infectious disease epidemiology (Tweedy *et al*. 2018). WGS can also help clarify the bacterial transmission between population groups by sampling bacteria from specific host groups.

Remote sensing technologies: Remote sensing is a rapid, non-invasive and efficient technique which can acquire and analyze spectral properties of earth surfaces from various distances, ranging from satellites to ground-based platforms. The use of remote sensing for national development started in India comparatively earlier than other developing countries. The first experiment that used remote sensing was on coconut root-wilt disease by Prof. Pisharoth Rama Pisharoty in Kerala in early 1970 (Dakshinamurti *et al.,* 1971). Professor Pisharoty is regarded as the 'Father of Remote Sensing' in India, who was also the founder Director of the Indian Institute of Tropical Meteorology, Pune in 1962. In the coconut root-wilt study, aerial photographs with 'Hasselblad camera' was taken in seven different combinations of wave bands from a helicopter flown at two different altitudes of 500 and 1000 feet. The photographic exposures included the color Ektachrome infrared film, ordinary black and white film and black and white panchromatic plus X with three different filters in red, blue and green bands.

Now a days, this technology holds promise in agricultural crop production including crop protection. Variability in the reflectance spectra of plants resulting from occurrence of disease and pests, allows their identification using remote sensing data. Various spectroscopic and imaging techniques like visible, infrared, multiband and fluorescence spectroscopy, fluorescence imaging, multispectral and hyperspectral imaging, thermography, nuclear magnetic resonance spectroscopy etc. have been studied for the detection of plant diseases. Based on the data acquired from these remote sensing systems and sensitivity analysis, a variety of remote sensing features are proposed and identified as surrogates in the detection and monitoring processes. They include (1) optical, fluorescence, and thermal parameters; (2) image-based landscape features; and (3) features associated with habitat suitability. Several of these techniques have great potential in phyto-pathometry. Remote sensing technologies will be extremely helpful to greatly spatialize diagnostic results and thereby rendering agriculture more sustainable and safer, avoiding expensive use of pesticides in crop protection. Different forms of remote sensing methods have been introduced for detecting and monitoring plant diseases and pests in many ways.

CRISPR-based diagnostics: Clustered Regularly Interspaced Short Palindromic Repeats (CRISPR) systems in addition to revolutionizing the genome-editing field, has given rise to a new generation of molecular diagnostic and POCT techniques offer highly specific and targeted detection of plant

viruses, and can also be used for genome editing to enhance plant resistance to viral infections. CRISPR-based diagnostics offer a promising avenue for rapid, on-site plant disease detection in India, particularly in resource-limited settings. CRISPR-Cas utilizes the adaptive immune system that preys on foreign nucleic acids and is broadly found in bacteria and archaea. The CRISPR-Cas system is generally composed of Cas proteins and CRISPR RNA (crRNA). The CRISPR-Cas family system is divided into two types and subdivided into six distinctive types based on their protein usage. The Class 1 system has types I, III, and IV, while the Class 2 system has types II, V, and VI (Paul and Montoya, 2020). CRISPR-Cas technology also can adapt itself and bring in a change in other living entities, such as plants. To provide resistance against plant diseases, CRISPR-Cas has been modified to prevent the plants from being infected. The CRISPR-Cas9-based genome editing methods are able to safeguard plants. Plants that showed resistance include *N. benthamiana* and Arabidopsis showed resistance against Merremia moasaic virus (MeMV), Beet severe curly top virus (BSCTV), Beet curly top virus (BCTV), Bean yellow dwarf virus (BeYDV) and and Tomato yellow leaf curl virus (TYLCV) (Hinge *et al.*, 2021).

Machine learning and AI: Automated technologies to detect plant diseases are currently essential. They prevent crop diseases from occurring frequently and the losses that follow from them. The automated disease detection system that uses AI follows predetermined steps. The procedures involve several steps, including installing various sensors in the agricultural field to collect and record plant images. The collected images are then processed and segmented to be used as data in machine learning algorithms. The Machine learning models then predict whether a leaf is healthy or diseased (Ayaz *et al.*, 2019). To optimize their use, it is essential to identify relevant and practical models and understand the fundamental steps involved in automated detection.

Microarray technology: Microarray technology is utilized in India for plant disease diagnostics, enabling the simultaneous detection of multiple pathogens in a single reaction. It consists of pathogen-specific DNA sequences (called DNA probes) that are immobilized on a solid surface like a glass slide. Total RNA is extracted from infected plant tissue and converted to cDNA. This cDNA is then amplified using PCR with pathogen-specific primers and labeled with a fluorescent dye. The labeled cDNA is then hybridized to the microarray, where it binds to its complementary DNA sequences on the array. After washing away unbound material, the array is scanned using a CCD camera and suitable software to visualize the fluorescent signal, indicating the presence and identity of pathogens. This technique uses pathogen-specific DNA sequences immobilized on a solid surface, allowing for the detection of multiple pathogens, including those that cause disease complexes. Microarrays allow for the simultaneous detection of multiple pathogens in a single test, which is crucial as plants

are often infected by multiple pathogens.

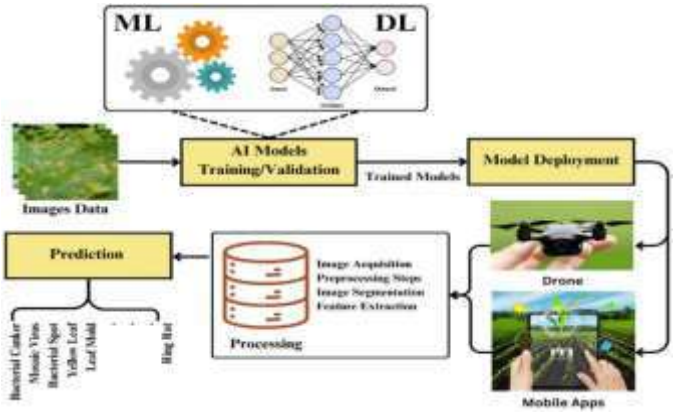

Fig. 1: Overview of real-time disease detection in plants

Benefits of new-generation diagnostic tools

Enhanced Sensitivity and Specificity: New techniques offer improved accuracy and precision in detecting plant pathogens compared to traditional methods. CRISPR-Cas systems like Cas12a and Cas13a can detect plant viruses with higher sensitivity than traditional PCR assays. For instance, a CRISPR/Cas12a-based method successfully detected the tomato leaf curl virus (ToLCKV) in tomato plants at a lower concentration than PCR, demonstrating increased sensitivity.

Earlier Detection: Advanced diagnostic tools enable early detection of diseases, allowing for timely interventions and potentially preventing widespread outbreaks. Isothermal amplification techniques like LAMP and RPA combined with CRISPR/Cas systems can diagnose plant viral infections within 30 minutes of collecting a leaf sample, enabling rapid decision-making for managing potential outbreaks.

Improved Scalability: Remote sensing technologies and high-throughput sequencing enable large-scale disease monitoring and pathogen identification, crucial for managing plant diseases across vast agricultural areas. Satellite imagery and drones equipped with hyperspectral and multispectral sensors can monitor large agricultural fields in India to detect disease symptoms or changes in plant health before visible signs appear.

Cost-Effectiveness: While some advanced techniques may have high initial costs, they can offer long-term cost savings through reduced pesticide use, minimized crop losses, and optimized resource management. CRISPR-based approaches for developing disease-resistant crops, such as wheat resistant to powdery mildew, could significantly reduce reliance on chemical fungicides, leading to lower costs for farmers and reduced environmental impact.

Sustainability: By enabling early detection, targeted interventions, and the development of disease-resistant crops, new diagnostic tools contribute to more sustainable agricultural practices. CRISPR technology can be used to develop crops resistant to soil salinity, a widespread problem in coastal regions of India like Gujarat and Rajasthan. By enabling crops to thrive in challenging conditions, CRISPR reduces pressure on fertile land and promotes sustainable land use practices.

By enabling early detection, targeted interventions, and the development of disease-resistant crops, new diagnostic tools contribute to more sustainable agricultural practices.

Summary and Conclusion

Early disease detection has become a cornerstone of modern healthcare, driving significant improvements in patient outcomes by enabling timely interventions. The convergence of innovative technologies like biosensors, microarray technology, high-throughput sequencing (NGS), remote sensing, CRISPR-based diagnostics, and machine learning/AI has substantially enhanced the capacity for early disease identification. Biosensors, for instance, detect biological markers with remarkable speed and precision, offering non-invasive, real-time monitoring through wearable devices. Microarray technology provides insights into gene expressions, enabling the identification of genetic markers for diseases such as cancer, diabetes, and autoimmune disorders. High-throughput sequencing (NGS) has revolutionized the diagnostic landscape by allowing for the sequencing of entire genomes, thus facilitating the detection of genetic mutations and variations linked to various diseases and enabling personalized treatments. Remote sensing technologies, including satellite imaging and drones, contribute to environmental health monitoring by tracking disease outbreaks or environmental factors that influence diseases like vector-borne illnesses. CRISPR-based diagnostics, utilizing the precision of CRISPR technology, offer rapid, cost-effective detection of specific pathogens and genetic mutations, making it possible to conduct point-of-care tests for early diagnosis of infectious and genetic diseases. Machine learning and AI are increasingly integrated into healthcare, processing large-scale data from genomics, clinical records, and medical imaging to detect patterns, predict disease progression, and recommend personalized treatment strategies. All these technological advancements represent a transformative shift in early disease detection, providing unparalleled precision, speed, and scalability. Together, they not only improve disease detection at molecular and environmental levels but also pave the way for personalized treatments, better resource allocation, and enhanced patient care. Despite challenges such as the need for further validation, data privacy issues, and regulatory hurdles, these innovations hold great promise for reducing disease burden and improving global health outcomes in the near future.

Bitter Gourd (*Momordica charantia*): A Natural Powerhouse of Health

Jyotsanaben N. Chaudhary and Riddhi V. Joshi

Introduction

Momordica charantia often called bitter-melon, balsam pear, bitter gourd or bitter squash is a tropical and sub-tropical vine of the family *cucurbitaceae* widely found in Asia, Africa and Caribbean for its bitterest fruits edible fruit. It originated from India and was carried to China in the 14th century. 'Jhaar Karela' (*Momordica charantia* var. abbreviata) is a variety of bittergourd found in wild. Its varieties differ substantially in the shape, size, texture and bitterness. Its fruit, although bitter in taste, is highly valued for its nutritional richness and bioactive phytochemicals, making it both a functional food and a traditional medicinal agent.

Nutritional Profile: Bitter gourd is often overlooked due to its bitter taste, but it contains higher nutritional value compared to other cucurbits such as pumpkin, squash, cucumber, and zucchini (Krawinkel and Keding, 2006). The fruit is rich in vitamins (A, C, E, folate, thiamine, riboflavin, niacin) and essential minerals (potassium, calcium, zinc, magnesium, phosphorus and iron) (Joseph and Jini, 2013). Vitamin C is especially abundant, with young fruits showing the highest concentrations (Goo *et al*., 2016). Seeds are also nutrient-dense, being excellent sources of high-quality proteins that meet FAO/ WHO/UNU amino acid requirements for preschool children (Nagarani *et al.,* 2014).

Table 1: Nutritional Composition of Bitter Gourd (per 100 g edible portion)

Constituent	Amount (per 100 g)
Energy	17-20 kcal
Water (%)	83.2-92.4
Lipids (%)	0.1-1
Carbohydrates (%)	4.2-9.8
Proteins (%)	1.6-2.9
Fiber (%)	0.8-1.7
Ash (%)	7-18
Calcium (mg)	20-50
Phosphorus (mg)	70-140
Iron (mg)	2.2-9.4
Magnesium (mg)	16
Sodium (mg)	3-40
Potassium (mg)	8-170
Zinc (mg)	0.1
Manganese (mg)	0.08-0.32
Copper (mg)	0.18-5
Vitamin A (IU)	210-220
Vitamin C (mg)	70-120
Thiamine (mg)	0.05
Riboflavin (mg)	0.03
Niacin (mg)	0.4
(Adapted from Behera *et al.,* 2008; Nagarani *et al*., 2014; Sorifa, 2018; Saeed *et al*., 2018)	

Biochemical Constituents and Health Roles

Triterpenoids and Saponins

Charantin, Momordicosides, Karavilosides

✓ Exhibit hypoglycemic properties by improving

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glucose uptake and reducing gluconeogenesis.

- ✓ Regulate lipid metabolism and reduce cholesterol.

Proteins and Peptides

Polypeptide-p: An insulin-mimetic peptide that reduces blood glucose.

MAP30 (Momordica antiviral protein, 30 kDa): Demonstrates antiviral and anticancer potential.

Flavonoids and Phenolic Compounds

Quercetin, Rutin, Catechin, Gallic acid

- ✓ Potent antioxidants that protect against oxidative stress.
- ✓ Contribute to anti-inflammatory and cardioprotective effects.

Sterols

β-sitosterol, Campesterol, Stigmasterol

- ✓ Improve cholesterol balance and support cardiovascular health.

Other Micronutrients

Vitamin C: Boosts immunity and collagen synthesis.

Folate: Crucial for DNA synthesis and pregnancy health.

Potassium: Maintains fluid balance and blood pressure regulation.

Nutritional and Health Benefits

Diabetes and Metabolic Health

- ✓ Bitter gourd's low energy density, high fiber, and hypoglycemic phytochemicals make it effective in glycemic control.
- ✓ Enhances insulin sensitivity, lowers postprandial glucose, and supports weight management.

Antioxidant and Anti-Aging

- ✓ Rich in vitamin C and polyphenols, bitter gourd neutralizes reactive oxygen species (ROS).
- ✓ Protects cells from oxidative stress, slowing aging and reducing risk of chronic diseases.

Cardiovascular Protection

- ✓ Fiber, potassium, and sterols help regulate blood pressure and cholesterol.
- ✓ Reduces atherosclerotic risk by lowering LDL and triglycerides.

Digestive and Liver Health

- ✓ High dietary fiber promotes gut health and bowel regularity.
- ✓ Exhibits hepatoprotective effects, protecting the liver from toxins.

Immune and Skin Health

- ✓ Vitamin C and bioactive proteins support the immune response.
- ✓ Traditional use shows benefits in acne, eczema, and wound healing due to blood-purifying and antioxidant effects.

Safety and Precautions

- ✓ Excess consumption may cause gastrointestinal discomfort or hypoglycemia (especially in individuals on antidiabetic drugs).
- ✓ Pregnancy caution: Certain biochemical compounds may stimulate uterine contractions.
- ✓ Seeds of mature fruits should be avoided in large amounts due to potential toxicity.

Conclusion

Bitter gourd is both a nutritionally rich food and a biochemical reservoir of health-promoting compounds. Its unique combination of low calories,

high fiber, vitamins, minerals, and bioactive phyto-chemicals contributes to antidiabetic, anti-oxidant, cardioprotective, hepatoprotective and immuno-modulatory effects. While traditional and preclinical evidence is strong, more robust clinical trials are required to establish standardized therapeutic recommendations. Thus, bitter gourd may be rightly regarded as a functional food and natural powerhouse of health, with wide applications in nutrition and preventive medicine.

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Mass Rainwater Harvesting

Sagar

Abstract

Water scarcity has emerged as a global challenge due to rising population, climate change, and overuse of natural resources. Mass rainwater harvesting is an effective strategy that captures and stores rainwater for household, agricultural, and industrial use. This paper discusses its importance, major techniques, community role, challenges, and future potential as a sustainable solution to water insecurity.

Introduction

Water has always been at the center of human survival and development. Yet today, water shortages have become frequent in many regions. Cities struggle to provide drinking water, and farmers are often unable to irrigate their crops. Over-extraction of groundwater and irregular rainfall patterns worsen the crisis. In this situation, mass rainwater harvesting offers a practical and sustainable way forward. Unlike depending solely on rivers or wells, this practice uses rainfall a resource that is freely available but often wasted. When communities adopt rainwater harvesting on a large scale, the benefits extend beyond individuals to entire regions.

Why Mass Rainwater Harvesting Matters

Rainwater harvesting is more than just saving water. It provides solutions to multiple problems simultaneously:

- ✓ Supplementing household and agricultural water supply during shortages.
- ✓ Reducing pressure on groundwater resources.
- ✓ Minimizing street flooding by diverting excess runoff.
- ✓ Enhancing soil moisture, which supports crop production.
- ✓ Offering a low-cost and eco-friendly method of water management.
- ✓ Contributing to long-term climate resilience by improving local water availability.

Techniques of Mass Rainwater Harvesting

Different techniques are suitable for different landscapes and communities. Some widely used approaches include:

Rooftop Harvesting: Collecting rainfall from roofs of houses, schools, or factories into tanks or pits.

Surface Runoff Storage: Constructing ponds, tanks, and trenches to capture water from open fields and roads.

Roadside Systems: Building slopes and underground drains along streets to direct rainwater into storage wells.

Revival of Traditional Systems: Restoring ponds, stepwells, and community tanks that historically

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served as reliable water sources.

Aquifer Recharge: Using recharge wells to send excess rainwater into the ground to improve underground reserves.

Practical Examples

The effectiveness of rainwater harvesting can be seen in many regions:

- ✓ In several Indian states, making rooftop systems compulsory for urban buildings has helped stabilize groundwater levels.
- ✓ Community-led projects in large cities have reduced dependence on expensive tanker supply by setting up shared storage tanks.
- ✓ In arid villages, the revival of traditional ponds and earthen dams has transformed dry land into water-secure areas.
- ✓ Across parts of Africa, small check dams on seasonal streams have provided thousands with access to fresh water in dry months.

These examples show that with proper planning, both cities and villages can benefit greatly from this practice.

Policy and Community Participation

Government and community involvement play a central role in scaling up rainwater harvesting. Policies can make systems mandatory in new constructions, provide tax benefits for households that adopt the method, and support large-scale projects through funding. At the same time, community participation ensures maintenance and collective ownership. Awareness drives, workshops, and training programs can help people understand the value of rainwater and encourage them to treat it as a resource rather than waste.

Challenges in Adoption

Even though the benefits are clear, several challenges slow down large-scale adoption:

- ✓ Limited awareness and knowledge of technical methods.
- ✓ Poor upkeep of storage tanks and recharge pits once installed.
- ✓ Financial barriers for families or institutions to set up systems.
- ✓ Lack of strong policy enforcement in many regions.
- ✓ Rapid urban growth reducing open spaces for water storage.
- ✓ Addressing these issues is necessary for rainwater harvesting to become mainstream.

Possible Solutions

The following measures can strengthen adoption of mass rainwater harvesting:

- ✓ Governments should provide subsidies and enforce strict building codes.
- ✓ Schools and colleges can integrate rainwater harvesting into their campuses and curriculum.
- ✓ Communities can form local groups to manage shared water storage systems.
- ✓ Awareness campaigns can highlight success stories and demonstrate low-cost models.
- ✓ Technology such as sensors and digital monitoring can track storage levels and recharge efficiency.

Future Potential

Rainwater harvesting is not just a short-term relief measure but a long-term strategy for sustainable development. In urban areas, it can be linked with smart city projects and green infrastructure like rooftop gardens and parks. In rural areas, it can secure irrigation needs and protect communities from drought. Globally, it supports the achievement of Sustainable Development Goals related to clean water, sustainable cities, and climate action. With the right approach, rainwater harvesting can become a central pillar of water management strategies in the future.

Conclusion

Rainwater harvesting is simple in concept but powerful in impact. By extending it from individual households to entire communities and cities, water shortages can be reduced, agriculture can be supported, and urban flooding can be minimized. The combined effort of policymakers, citizens, and technology can make rainwater harvesting an essential solution for water security in the coming decades.

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Nanotechnology in Horticulture: Applications of Nanoparticles in Fruit Crop Protection, Nutrition and Shelf-life Extension

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Introduction

Advances in nanotechnology are revolutionizing horticultural practices, particularly in the management of fruit crops. By manipulating materials at the nanoscale (1-100 nm), researchers have developed innovative solutions for fruit crop protection, nutrition, and shelf-life extension. Nanomaterials engineered for unique physical, chemical and biological properties support sustainable, efficient production, with lower inputs and improved outputs. This article explores key nanotechnology applications in horticulture aimed at PhD-level understanding, delving into real-world examples and mechanisms.

Nanoparticles in Fruit Crop Protection

Targeted Pest and Disease Management

- ✓ Nano-pesticides are formulated to encapsulate active ingredients, ensuring controlled, efficient release at the site of infection. This drastically reduces chemical runoff and environmental damage compared to traditional pesticides. For instance, nano-ZnO and nano-CuO have been used to combat citrus canker, reducing infection rates from over 60% to below 25% in field studies on grapefruit and orange. Nano-sulphur and nano-chitosan formulations have shown over 90% inhibition of fungal growth in apples and strawberries, respectively
- ✓ Nano-encapsulated pheromone gels improve fruit fly trapping in guava orchards, contributing to more effective pest management.

Mechanism: Nanoparticles facilitate penetration into plant tissues and restrict pest or pathogen growth by targeted release, improved adhesion to plant surfaces, and enhanced stability.

Nanoparticles in Fruit Crop Nutrition

Nano-fertilizers

- ✓ Nano-fertilizers are engineered for slow, sustained nutrient release, tailored to match plant absorption rates. This improves nutrient use efficiency, reduces environmental leaching, and optimizes growth. For example, nano-calcium for apples enhances fruit quality and storability; nano-boron boosts vegetative growth and yield in mangoes; nano-iron and nano-boron increase sugar content and yield in pomegranate.
- ✓ Carbon nanotubes (CNTs) applied to grapevines increase leaf area, shoot growth, and overall productivity.
- ✓ Nano-silicon oxide enables strawberries to tolerate soil salinity, while nano-zinc increases leaf number and vigor.

Mechanism: Nano-fertilizers have high surface area, which enhances interaction with both root and

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leaf tissues, enabling efficient uptake even under stress conditions. They also promote deeper rooting and robust plant development.

Nanoparticles for Shelf-life Extension

Edible Nanocoatings and Packaging

- ✓ Edible coatings enriched with nanoparticles (like chitosan, zinc oxide, silver) form thin protective films on fruit surfaces, creating barriers to moisture and gas exchange, slowing ripening and spoilage. Chitosan nanoparticle coatings have extended apricot shelf-life by up to nine days at room temperature, and over 30 days in cold storage. Similar effects have been noted in mangoes, strawberries, and apples.
- ✓ Nanoparticle-enriched packaging utilizes materials such as nanocellulose, nano-chitosan, and starch-based composites for antimicrobial, antioxidant, and barrier properties. Silver nano-particles in packaging films can inhibit bacteria and fungi, delaying spoilage and prolonging shelf life. Composite films combining silver and titanium dioxide are used for strawberries, apples, and pineapple juice packaging.

Mechanism: Nano-films and coatings restrain microbial growth, delay moisture loss, and modulate ethylene exchange, thus preserving texture, color, and nutritional quality, minimizing post-harvest waste.

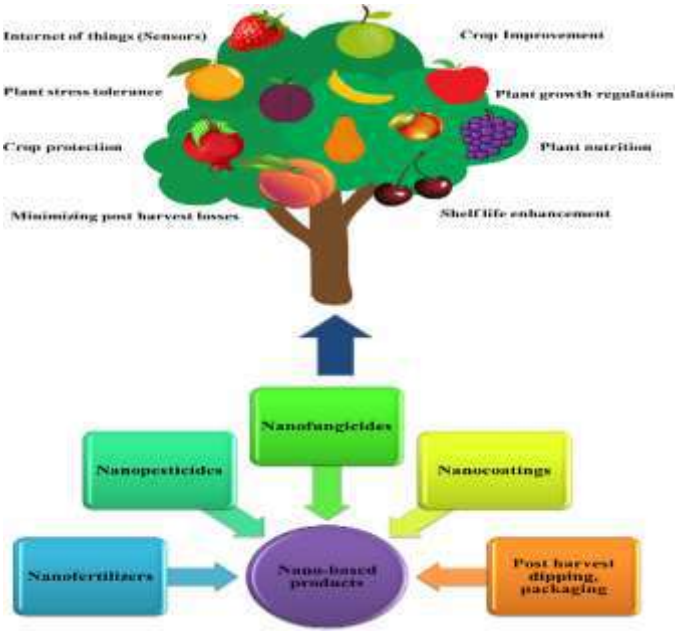
Seed Coating with Nanoparticles

- ✓ Nanomaterial seed coatings (ZnO, SiO_2) enhance germination, water and nutrient uptake, and resilience against environmental stress. These coatings serve as barriers against pests and diseases at vulnerable growth stages, improving seed-to-soil contact, reducing seedling mortality, and boosting overall crop establishment.
- ✓ Nano-seed priming also increases aquaporin gene expression for better water absorption and triggers enzymatic activity for faster starch mobilization in seeds, supporting robust early growth.

Role in Mitigating Abiotic Stress

Stress Tolerance: Nanoparticles are pivotal in helping fruit crops withstand drought, salinity, and temperature extremes. They regulate key physiological processes like hormone metabolism, osmolyte biosynthesis, and antioxidant activity resulting in improved survival, growth, and productivity under environmental stress.

Mechanism: Nanoparticles enter through roots and leaves, boosting stress-responsive gene expression, closing stomata to reduce water loss, and protecting photosynthetic machinery from oxidative damage.



Biosensors and Precision Agriculture: Nano-biosensors integrated with smart farming systems enable real-time monitoring of soil health, moisture, nutrient status, and early detection of pathogens. This data-driven approach helps optimize resource use and supports precision management.

Modern Nanotechnology Research and Implementation in Fruit Crops

Contemporary research in nanotechnology for horticulture is marked by the adoption of innovative techniques and equipment designed to improve crop quality, protection, and shelf life.

Nano-Coating Packaging for Fruits: Recent advances enable the packaging of fruits such as strawberries and apples in transparent nano-composite films that contain silver or zinc oxide nanoparticles. These films act as barriers against moisture and microbial contamination, resulting in superior preservation of fruit visual and nutritional quality over time.

Nano-Fertilizer Foliar Application: In field-based research, fruit crops are treated with nano-fertilizers in the form of fine mist sprays. This method ensures an even distribution of nutrients, facilitating better absorption through leaves and promoting robust plant growth and fruit development.

Seed Coating Process with Nanoparticles: Seeds are coated with nanoparticles, which often results in colored or glossy surfaces. This enhancement improves seed germination rates by promoting efficient water absorption and nutrient uptake. The process also boosts seedling vigor and ensures better crop establishment.

Chitosan Nanoparticle Edible Coatings: Studies have demonstrated that applying chitosan-based nanoparticle coatings on fruits, such as apricots, significantly extends their shelf life. When compared with uncoated samples, coated fruits maintain firmness and vibrant color for longer periods in storage, highlighting the protective effect against physical and microbial degradation.

These innovations illustrate how nanotechnology is reshaping fruit crop management, offering practical solutions for postharvest preservation, nutritional enhancement, and sustainable agricultural practices in horticulture.

Safety, Regulation, & Future Prospects

Challenges

- ✓ Concerns remain about toxicity, regulatory approval, environmental impact, and cost-effectiveness. “Green synthesis” methods using plant extracts or biological agents are being developed for safer nanoparticle production.
- ✓ Regulatory standards are evolving to address environmental fate, consumer safety, and long-term efficacy of nano-enabled products in horticulture.

Potential & Outlook: The future holds promise for wide adaptation of nanotechnology enhancing productivity, reducing post-harvest waste, ensuring food safety, and supporting sustainability in horticulture. Continued research and responsible implementation will be crucial.

Summary

Nanotechnology applications covering protection, nutrition and post-harvest preservation offer innovative, sustainable solutions to major challenges in fruit crop horticulture. Adoption and further research into these advances can revolutionize fruit production systems for the next generation of horticultural scientists and practitioners.

Impact of Organic and Natural Farming on Sustainable Agriculture

Aditya Kumar Giri, Simran, Ankit Singh Bhadauria and Shivam Dixit

Abstract

This article examines how organic and natural farming systems contribute to the three pillars of sustainability environmental integrity, economic viability and social equity while discussing trade-offs and pathways for scale. Drawing on landmark studies and program experiences, including Sikkim's statewide organic transition and Andhra Pradesh's Community-Managed Natural Farming (CMNF) program, we synthesize evidence on soil health, biodiversity, water quality, greenhouse-gas mitigation, farm profitability and resilience. We present a comparative table of farming systems and a schematic time-series graph of the global expansion of organic agriculture. The paper closes with policy and research priorities to responsibly accelerate adoption.

Introduction

Sustainable agriculture seeks to meet present food and nutrition needs without undermining the ecological foundations and socio-economic conditi-ons required for future generations. After decades of input-intensive agriculture, concerns around soil degradation, water pollution, biodiversity loss, greenhouse-gas emissions and farm indebtedness have prompted renewed interest in agroecological approaches. Organic farming (regulated and certified) and natural farming (e.g., Zero-Budget/ Community-Managed Natural Farming) are two prominent pathways that reduce dependence on synthetic fertilizers and pesticides, emphasize closed nutrient cycles and harness ecosystem services. Their impacts vary by context; nonetheless, a growing evidence base shows significant benefits to soil quality, water protection, pollinator conservation and long-term system resilience.

Concepts and Principles: Organic farming is governed by standards (e.g., NPOP, USDA Organic, EU), prohibiting synthetic fertilizers, most pesticides and GMOs and requiring practices such as crop rotation, green manures, composting and biological pest management. Natural farming is a family of practices that rely on on-farm and locally available inputs such as Jeevamrit/Beeyamrit, mulching and diversified cropping implemented through comm-unity facilitation rather than third-party certification. Both approaches seek to regenerate soil organic matter, enhance microbial activity and rebalance pest-natural enemy dynamics, but they differ in

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Table 1: Comparative overview of farming systems

Criterion	Conventional	Organic (Certified)	Natural (CMNF/ZBNF)
Primary inputs	Synthetic fertilizers, pesticides	Compost, green manure, biocontrols	On-farm ferments, mulches, diversity
Market model	Commodity pricing	Price premium via certification	Local/regional, group marketing
Compliance cost	Low	Moderate (inspection, paperwork)	Low (community verification)
Soil organic matter	Often stagnant/declining	Increases with rotations/manures	Increases with mulching/cover
Pest management	Chemical control	IPM & biocontrol	Habitat management, botanicals
Risk profile	Input price volatility	Transition yield dip, certification cost	Knowledge/management intensive

Note: Generalized comparison; outcomes vary by context and management

market orientation (certified premiums vs. local value chains) and compliance costs (inspection vs. self-verification).

Environmental and Biophysical Impacts

Soil: Both organic and natural systems increase soil organic carbon (SOC) by returning organic residues and reducing disturbance. Increased SOC improves aggregate stability, infiltration, cation-exchange capacity and nutrient retention. Microbial biomass and enzymatic activity typically rise, strengthening nutrient cycling.

Water: Eliminating or minimizing synthetic pesticides and nitrate-heavy fertilization reduces leaching and runoff risks. Mulching and ground cover lower evaporation and erosion. Buffer strips and diversified rotations further protect water bodies.

Biodiversity: Floral resources and reduced pesticide pressure support pollinators and natural enemies. Field-margin management and intercropping generate habitat heterogeneity, benefiting farmland birds, arthropods and soil fauna.

Climate: Lower embedded emissions from synthetic fertilizers, higher carbon sequestration in soils/ biomass and improved nitrogen use efficiency reduce net GHG footprints per hectare. Over time, resilience to heat and water stress improves via soil moisture conservation and diversified income streams.

Soil Health Mechanisms and Productivity

Soil organic inputs (composts, manures, crop residues) feed microbial communities that mineralize nutrients in synchrony with crop demand. Polycultures and legume rotations biologically fix nitrogen while mobilizing phosphorus and micro-nutrients. On average, yields during the first 2–3 transition years may dip relative to conventional systems as soil biological processes re-equilibrate; thereafter, yield gaps narrow, especially under stress conditions (drought, degraded soils), where organic and natural systems often outperform due to better water-holding and rooting depth.

Socio-economic Impacts

Cost structures shift markedly: external input purchases decline while labor and management skill demand rise. Organic farmers can capture premiums in certified markets; natural farming emphasizes input self-reliance and debt reduction. Community organizations producer companies, self-help groups and participatory guarantee systems enable aggreg-ation, quality assurance and fairer price discovery. Risk is mitigated by diversified enterprises (grains, pulses, horticulture, livestock, beekeeping).

Case Studies

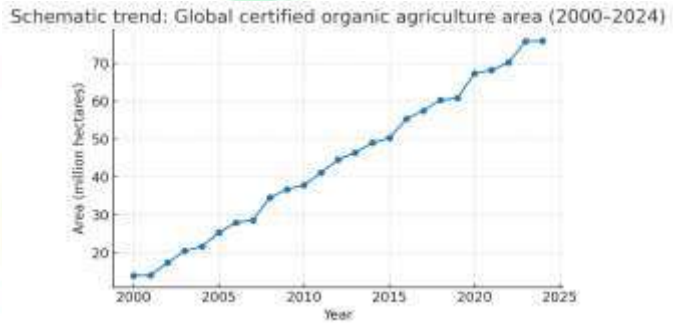
Sikkim, India - The First Fully Organic State: Sikkim transitioned all arable land to organic management through policy incentives, input substitution with composts and biofertilizers and capacity building. Outcomes reported include growth in high-value horticulture and tourism branding, improved soil quality indicators and enhanced farmer awareness. Initial challenges involved pest flare-ups and organic input supply chains; these were mitigated through extension, local input units and market development initiatives.

Andhra Pradesh - Community-Managed Natural Farming (CMNF): Andhra Pradesh scaled natural farming via community institutions (self-help groups and farmer facilitation) emphasizing Jeevamrit, Beejamrit, mulching and crop diversification. Program monitoring suggests reductions in input costs, improved net incomes and better resilience to dry spells. Social capital and peer learning were critical to adoption, while transition support (handholding, demonstrations) reduced perceived risk.

Long-Term Systems Trial (USA) - Rodale Institute: Long-term side-by-side comparisons of organic and conventional grain systems indicate comparable yields in normal years and higher organic yields under drought due to improved soil water retention. Energy use and GHG emissions per hectare are also lower in organic rotations that rely on legume nitrogen and cover crops.

Smallholder Horticulture - Mixed Cropping and Bee Integration: Mixed vegetable-pulse-spice systems with apiaries have demonstrated higher gross margins and ecosystem services (pollination) under organic and natural protocols. Post-harvest handling (shade drying, cold rooms, residue-free branding) adds value and reduces losses.

Global Expansion of Certified Organic Agriculture (schematic): The figure below presents a schematic trend of global certified organic agricultural land (2000-2024) to visualize the rapid expansion reported by international datasets. Values are indicative for illustration.



The Future of Organic and Natural Farming

Eight interlocking levers can accelerate responsible scale while safeguarding integrity:

Soil carbon and nutrient circularity: On-farm composting, biochar where appropriate, legume based rotations and precision nutrient budgeting.

Water-smart agroecology: Mulches, cover crops, micro-irrigation and water harvesting to buffer climate extremes.

Ecological IPM: Habitat manipulation, biologicals, decision support tools and minimal-risk botanicals.

Seed systems: Farmer-led participatory breeding for stress tolerance and nutritional quality; open-source seed commons.

Digital public goods: Agronomic advisories, traceability, residue testing and market intelligence for smallholders.

Inclusive value chains: PGS and Fairtrade models, local procurement for schools/hospitals and cold-chain for perishables.

Finance & risk tools: Transition credit, parametric weather insurance and carbon/ecosystem service payments with robust MRV.

Science & standards: Context-specific metrics (soil health, biodiversity, nutrition) and adaptive regulations to enable safe bio-inputs while deterring greenwashing.

Policy and Program Recommendations

- ✓ Targeted transition support for 3-5 years, tied to verifiable soil-health and pesticide-reduction outcomes.
- ✓ Invest in local bio-input production units and residue-testing labs; publish open dashboards to build trust.
- ✓ Strengthen extension through farmer-to-farmer learning networks and digital advisories in local languages.
- ✓ Expand climate finance for soil carbon sequestration and biodiversity co-benefits with conservative baselines.
- ✓ Encourage landscape-scale planning (corridors, riparian buffers) to amplify pollination and natural pest control.
- ✓ Support women-led enterprises in processing, branding and community seed banks.

Conclusion

Organic and natural farming are central pillars of sustainable agriculture when implemented with scientific rigor, community support and enabling markets. They regenerate soils, protect water and biodiversity, mitigate climate impacts and can enhance rural livelihoods. With smart policy, digital tools, inclusive value chains and continued research, these systems can supply an increasing share of safe, nutritious food while stewarding the ecosystems on which agriculture depends.

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Production Technology of Potato

Priyanka Deka and Pabitra Kumar Nath

Abstract

Potato production technology focuses improving potato yield, quality and sustainability in potato cultivation. These includes enhancing planting methods, effective pest and disease management, using improved seed variety and implementing efficient irrigation and fertilization strategies.

Introduction

Potato (*Solanum tuberosum*) is a native of South American continent, where it is used to grow as wild plant from about 7000-9000 years ago. In India Portugese traders first brought potato to India during the late 16th and early 17th century. India ranked second in terms of potato production in the world contributing about 12.52% of global production from 11.29% area under potato with an average yield of 22.31 t ha^{-1}.

Climate and Soil Requirement

Climate: Potato is a cool season crop. Potato is well recognized for its exact temperature and day length requirement for tuber formation. The minimum night temperature should be (12-18º C) and maximum day requirement should be 25-28º C. Therefore the crop is vulnerable to climate change. An increase in minimum temperature of above 21º C cause sharp reduction in the potato tuber yield. Sunshine along with cooler nights is essential for higher yields and reducing the spread of disease.

Soil Requirement: Potato can be grown in a wide range of soil. Well drained sandy loam, silty loam or loam, rich in organic matter are suitable. Soil should be friable, well aerated, deep, well supplied with organic matter and rich in humus. Alkaline or saline soils are not suitable for potato cultivation. Crop is well suited to acidic soils (pH 5-6.5) as acidic conditions tend to limit scab disease.

Field Preparation

Field preparation is done either manually or mechanically with power tiller or tractor depending on the size of land holding, topography and its accessibility. Field should be thoroughly ploughed to obtain a good tilth.It involves:

Ploughing: Deep ploughing should be done.

Leveling: Levelling is important for uniform distribution of irrigation water or to maintain soil moisture uniformly.

Harrowing: 3-4 harrowing are done.

Moreover, the fields are also forked to a depth of 25-30 cm and then clods are broken.

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The furrow should be prepared at 50 cm apart.

Varietal Selection: Variety selection depents on regional climate, cropping system, duration, availability of seed and intended market use. Some improved varieties include- K. Jyoti, K. Pukhraj, K. Khyati, K. Surya, K. Himalini, K. Chipsona I, K. Chipsona 3, Lady Rosetta, Yusi Maap, K. Mohan. Improved varieties offer traits such as higher yield, resistance to early and late blight and also few have early maturity.

Planting Technology

Time of Planting: The optimum time for planting is mid-October to mid-November.

Method of Planting: The sprouted tubers should be planted in furrows with sprouts facing upwards. Care should be taken to avoid sprout damage handling the tubers.

Seed Selection: Once the tubers arrive at farmers place, the bags are to be opened as soon as possible and all the tubers should be spread under diffused light in thin layers. Proper air circulation should be maintained at the place where seed tubers are spread. Virus free, healthy, medium sized sprouted tubers are to be selected for planting. Ideal size is about 2.5 cm in diameter (25-40 gm) with 3-4 healthy eye buds. Bigger sized tubers may be cut into pieces longitudinally with 2-3 eyes in each piece with frequent sterilization of the knives. Rotten tubers are not used as seed. Blind/ Unsprouted tubers are to be removed to avoid gap in between plants.

Seed Sources: Certified seeds of the recommended varieties are to be produced from Govt. or other recognized agencies.

Seed Treatment: In case of cut seeds, the pieces are to be dipped in carboxin @ 2 g in 1 litre of water for about 10 minutes. After treatment, the seeds are to be spread thinly and dried under shade for 48 hrs, or should be covered with moist gunny bags for 2-3 days for tuberization.

Seed Rate: The seed requirement is 22.5-25 q ha^{-1} when size of the tubers are about 2.5 cm in diameter (about 25 g) and planted with an intra-row spacing of 15 cm. Intra row spacing is increased with bigger sized tuber.

Nutrient Management

Nutrient	Recommended dose (kg ha^{-1})
Rainfed	
N	60
P_2O_5	50
K_2O	50
Irrigated	
N	120
P_2O_5	100
K_2O	100

- ✓ Apply entire quantity of fertilizer in furrows as basal applications.
- ✓ Cover with a thin layer of soil so that tubers do not come into direct contact with the fertilizers.
- ✓ Foliar spray of NPK 19:19:19 (75gm in 16 litre water) along with Zinc (50 gm in 16 litre water) can be done after 30-35 DAP AND 40-45 DAP.
- ✓ Foliar spray of 13:00:45 potassium nitrate (75 gm in 16 litre water) can be done55-60 DAP.
- ✓ Foliar spray of 00:00:50 Sulphate of Potash (75 gm in 16 litre water) can be done 65-70 DAP.

Irrigation Management

Potato is highly sensitive crop to moisture stresses (low and high). Both low and high moisture

conditions lead to low yield and increased potato defects and disease incidents. Furrow method of irrigation can be adopted.Three irrigations should be applied.

Critical stages: Stolon formation stage, tuber formation stage and tuber development stage.

Irrigation schedule

First irrigation: 25 DAP.

Second irrigation: 60 DAP.

Third irrigation: 80 DAP after the emergence of sprouts.

Each irrigation should be light, and half the ridge is submerged in water. In no case water should flow over the ridge.

Weeding and Interculture Management

Interculture Management

Earthing Up: Sufficient soil should be added up to the ridges to avoid tubers exposure to sun and provide enough space for tuber growth. Earthing up should be done 25-30 DAP before first and second irrigation. Earthing up minimizes greeing of tubers and maximizes tuber size that lead to maximum yield.

Roguing: Roguing is an important practice for producing high quality, disease free seed potato. During roguing, the off typeand disease infected plants along with tubers are uprooted and removed. These plants should be buried away from potato fields. It is done at three stages:

- ✓ 25-30 DAP-before plants canopy touch each other to spread viruses.
- ✓ 50-60 DAP- Some plants give virus symptoms at later stage.
- ✓ Just before haulms cutting- Off type and virus infected plants are checked again.

Haulm cutting: It is done manually 10-15 days before harvesting. Cutted haulms should be kept on the ridges to protect tubers from direct sunlight. After dehaulming there may be regrowth in some plants that may attract aphids and spread virus, this growth should be removed immediately to avoid contamination of viral diseases.

Weed Management

Weeds compete severely in initial growth phase.

Control Measures

Manual weeding: One or two intercultural operations may be necessary when weed infestation is high at 25-30 DAP.

Herbicides: Applying of Metribuzin @ 0.75 kg ha^{-1} or 100 gm $bigha^{-1}$ (about 2-3 DAP) to get optimum weed control and tuber yield.

Pest and Disease Management

Major Insect-Pests	**Management**
Potato Tuber Moth	Imidacloprid or Thiamethoxam can be sprayed at a regular intervals of 2-3 weeks
Cut worm	Infected fields can be flooded. Handpicking and destroying the larvae in morning and evening hours.
Red Ant	Application of wood ash and mustard oil cake can be used
Aphids	Spraying of insecticides like Imidacloprid & Thiamethoxam
Green Leaf hopper	Spraying of insecticides such as Thiamethoxam or Emamectin benzoate
Major Disease	
Early blight	Spraying of fungicides i.e. Propineb. It can be sprayed in an interval of 7 -10 days. Planting of less susceptible variety is also important as well as using of resistance varieties.

Late blight	Spraying of fungicides i.e. Propineb and alternatively Iprovalicarb can be done at an interval of 7-10 days. If the disease becomes extremely severe Dimethomorph 50 % WP can be sprayed.
Bacterial wilt	Rouging out the infected Plants. Lime can be used as soil amendments to help control the disease.
Mosaic	Rouging out the infected Plants. Spraying of insecticides i.e. Imidacloprid, Emamectin benzoate & Thiamethoxam can be done

Harvesting and Post Harvest Management

Harvesting: Harvesting of tubers is done 10-15 days after dehaulming with the help of digger or manually. At harvesting the soil moisture in the field should be optimum to avoid damage of the tubers. Harvesting is done by digging the tubers carefully to avoid cuts and bruises.

Seed curing: After harvesting, tubers should be shifted to shade to protect from direct sunlight for skin hardening. The heaps are made in shade or well ventilated room.

Grading: Potato tubers are graded in four grades viz.

- ✓ Small size i.e. below 25 gm (30 mm).
- ✓ Medium Size 25-60 gm (30-45 mm).
- ✓ Large size 60-100 gm (45-55 mm) and
- ✓ Extra large size above 100 gm (> 55mm).

Seed Treatment: Tubers are washed in clean water and then sprayed or dipped in 3% solution of boric acid for 15-20 minutes. Treated tubers should be dried properly under shade before packing. Use of 4 cm thick layer of shade dried Neem or Eucalyptus leaves under and over stored tubers help in controlling potato tuber moth.

Packing and Storage: After sorting and grading, potatoes are kept in clean jute bags or net bags. New bags are used for packing the potatoes for prevention of disease and pest and are also labelled properly to avoid mixing of produce before transferring to cold storage.

Conclusion

Producing potato by following these technologies significantly impacts quantity and quality of the potato crop. Potato production is achieved by traditional farming techniques and modern technology including proper land selection, soil management quality seed potatoes. Precision farming technologies like soil and plant sensing can help in optimizing resource utilization thereby improving yields. By embracing these technologies and practices, potato farmers can enhance their productivity, quality of their produce is improved and contribute to environmentally friendly farming practices.

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Next Generation Plant Protection: Leveraging Epiphytic and Endophytic Microorganisms for Sustainable Agriculture

Ankita Amisha

Abstract

The global shift toward sustainable agriculture has positioned plant microbiome interactions as a promising frontier for reducing dependence on synthetic pesticide applications. Epiphytes and endophytes, two distinct but equally important microbial communities, play crucial roles in plant health management through various mechanisms including disease suppression, growth promotion and enhancing stress tolerance. This work elucidates the functional roles of epiphytic and endophytic microorganisms in plant defence systems, analyzing their synergistic interactions and commercial viability for integrated disease management.

Introduction

Modern agriculture faces unprecedented challenges including climate change, pesticide resistance, environmental degradation and growing demands for global food security. Traditional plant health management approaches, heavily reliant on synthetic pesticides, have contributed to agro-ecosystem imbalance, microbial community disruption and selective pressure for resistant pathogen genotypes (Glare *et al.*, 2012). These beneficial microorganisms present a promising path for developing sustainable plant health management strategies. Epiphytes and endophytes represent two major categories of plant associated microorganisms that have gained significant attention in recent years. While epiphytes colonize external plant surfaces, endophytes establish in intercellular spaces and vascular systems while maintaining mutualistic relationships with their hosts (Hardoim *et al.*, 2015). Both microbial communities offer unique advantages for sustainable agriculture through their diverse mechanisms of plant protection.

Understanding Epiphytes and Endophytes

Epiphytes: The External Guardians

Epiphytes are microorganisms that live on external plant surfaces, including leaves, stems, flowers and fruits. These microorganisms primarily consist of bacteria, fungi, yeasts and algae that form complex ecological networks on plant surfaces (Vorholt, 2012). Epiphytic community is governed by host plant genotype, microclimatic parameters, spatial distribution patterns and temporal environmental fluctuations.

Endophytes: The Internal Allies

Endophytes are microorganisms that colonize internal plant tissues while maintaining a mutualistic relationship with their hosts.

These microorganisms colonize all major

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plant organs including roots, stems, leaves, seeds and flowers (Santoyo *et al.,* 2016). Endophytes are typically classified as bacterial or fungal endophytes, each contributing differently to plant health.

Mode of action of epiphytes and endophytes

Direct Antagonistic Mechanisms

Antibiotic Production: Many epiphytic and endophytic microorganisms produce secondary metabolites with antimicrobial properties. *Bacillus* species, commonly found as both epiphytes and endophytes, synthesize bioactive metabolites with potent antifungal and antibacterial properties against diverse plant pathogens (Ongena and Jacques, 2008). Similarly, endophytic fungi like *Trichoderma* species produce metabolites including trichodermin and gliotoxin that inhibit various plant pathogens.

Ecological niche competition: Epiphytic and endophytic microbes limit pathogen establishment through nutrient depletion and niche occupation. (Lindow and Brandl, 2003). The rapid colonization ability of beneficial microorganisms often prevents pathogen establishment.

Hyperparasitism and Mycoparasitism: Certain epiphytic and endophytic fungi demonstrate hyperparasitic behaviour against plant pathogens. *Trichoderma* species, can parasitize other fungi through mechanisms including coiling around hyphae, forming appressoria and producing cell wall degrading chitinases and glucanases (Druzhinina *et al.,* 2011).

Indirect Mechanisms

Induced Systemic Resistance (ISR): Endophytic and epiphytic microorganisms can trigger plant defence responses through ISR, a process that enhances plant resistance to various pathogens. This process activates plant defence through ethylene signalling and jasmonic acid cascades (Pieterse *et al.,* 2014). *Bacillus subtilis* induce systemic resistance in various crops through the production of elicitor compounds.

Systemic Acquired Resistance (SAR): Some plant associated microorganisms can induce SAR, a resistance mechanism effective against bacterial, fungal and viral pathogens. This mechanism triggers salicylic acid production and pathogenesis related protein synthesis across plant tissues (Durrant and Dong, 2004).

Epiphytes and Endophytes in Sustainable Agriculture

Foliar Disease Management: Epiphytic species such as *Pseudomonas fluorescens* and *Bacillus subtilis* effectively suppress leaf diseases across diverse cropping systems. These bacteria inhabit leaf surfaces and defend against pathogenic fungi and bacteria using diverse protective mechanisms (O'Brien, 2017). Commercial products like Serenade (*Bacillus subtilis*) have demonstrated efficacy against powdery mildew, grey mould and fire blight.

Soilborne Disease Suppression: Endophytic microorganisms, particularly root associated bacteria and fungi, play crucial roles in suppressing soilborne pathogens. *Trichoderma* species have been used for management root rot diseases caused by *Fusarium, Pythium* and *Rhizoctonia* species (Hermosa *et al*.,

2012).

Post harvest disease management: Epiphytic yeasts and bacteria have shown promise for managing post harvest pathogens in stored crops. *Candida oleophila* and *Cryptococcus laurentii* have been used for suppression of *Botrytis cinerea* and *Penicillium expansum* (Droby *et al.*, 2009).

Nutrient Management: Phosphate solubilizing bacteria and nitrogen fixing endophytes enhance plant nutrient uptake, decreasing reliance on synthetic fertilizers. *Azospirillum* species, common grass endophytes, can fix significant amounts of nitrogen while promoting root development through auxin production (Bashan and de-Bashan, 2010).

Stress Tolerance: These microorganisms improve plant resilience against environmental stresses such as drought, salt exposure and heavy metal contamination (Glick, 2014). ACC deaminase producing endophytes lower plant ethylene concentrations during stress conditions, enhancing tolerance.

Conclusion

The successful implementation of epiphyte and endophyte based plant health management requires a multidisciplinary approach involving microbiologists, plant pathologists, agricultural engineers and extension specialists. As global agriculture faces increasing pressure to become more sustainable while meeting growing food demands, utilization of beneficial plant microbe interactions offers a promising path forward. Epiphytic and endophytic microorganisms play a central role in this integrated approach, for advancing sustainable, high yielding agricultural systems.

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Decoding Seed Vigour through Bio-Chemical Tests

Janapareddy Rajesh and Bandela Chandana

Seed vigour: The sum of those properties of seed which determine the potential level of activity *i.e.*, rapid and uniform production of healthy seedlings and stand establishment under a wide range of field conditions is considered as seed vigour. Seed vigour can be measured by various tests *viz.*, physical tests, performance tests, stress tests, chemical and bio-chemical tests.

Bio-chemical tests for seed vigour analysis

Electrical conductivity (EC) test

Principle: The Electrical Conductivity (EC) test is based on the principle that vigorous seeds have intact and efficient cell membranes, which prevent excessive loss of electrolytes during imbibition. When seeds absorb water, ions such as potassium (K^+), calcium (Ca^{2+}), magnesium (Mg^{2+}), and phosphate (PO_4^{3-}) may leak out through damaged or deteriorated membranes. The amount of ion leakage is directly related to the degree of seed deterioration and loss of vigour. This leakage increases the electrical conductivity of the seed soak water, which is measured using a conductivity meter. Thus, higher EC readings indicate lower seed vigour, while lower EC values reflect higher seed vigour.

- ✓ EC was expressed as µS cm^{-1} g^{-1}.
- ✓ Used for wide range of crops like cereals, pulses, oilseeds and vegetable seeds etc.

Tetrazolium test

Principle: The tetrazolium test is a biochemical assay used to assess seed viability and vigour by evaluating the activity of dehydrogenase enzymes involved in seed respiration. These enzymes are active only in living cells, and they catalyze the reduction of 2,3,5-triphenyl tetrazolium chloride (TTC) which is a colourless, water-soluble compound into a red, insoluble formazan compound. Viable and vigorous cells with intact respiration systems reduce TTC and stain cherry red. Whereas, dead or deteriorated cells lack metabolic activity and remain unstained or weakly stained.

- ✓ Used for wide range of crops like cereals, pulses, oilseeds and vegetable seeds etc.

Free sugar acids test

Principle: The free sugar acids test is based on the concept that seed deterioration and ageing cause increased breakdown of complex carbohydrates, particularly starch and structural polysaccharides, into simpler forms like free sugars and organic acids. These soluble sugars and acids accumulate in seed tissues and leak into the surrounding medium during imbibition. The test estimates the amount of free sugars (*e.g.*, glucose, fructose) present in the seed

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leachate using a colorimetric method, typically involving anthrone reagent. Upon heating, anthrone reacts with sugars to form a blue-green complex, the intensity of which is proportional to the sugar concentration. The absorbance is measured using a spectrophotometer at 620 nm. A higher sugar content in the seed leachate indicates greater membrane damage, biochemical deterioration, and lower seed vigour.

- ✓ It was expressed as mg g^{-1} seed (or) mg l^{-1} leachate.
- ✓ Used for crops like cereals and soybean.

Free fatty acid test

Principle: The Free Fatty Acid (FFA) test is based on the concept that seed ageing and deterioration lead to the breakdown of membrane lipids through lipolysis and lipid peroxidation. This process results in the release of free fatty acids, which accumulate in the seed tissues. Healthy, vigorous seeds have well-preserved membrane systems and relatively low levels of free fatty acids. In contrast, deteriorated or low-vigour seeds exhibit higher FFA content, which is indicative of oxidative damage to cellular membranes, especially in oil-rich seeds like groundnut, soybean, sunflower, and castor. The FFA content is estimated by extracting the oil from seeds and titrating it with a standard alkali (NaOH or KOH) solution. The acid value, which represents the amount of KOH required to neutralize the free fatty acids in 1 gram of oil, is calculated. A higher acid value indicates greater deterioration and lower vigour.

- ✓ It is expressed as percentage (%).
- ✓ Widely used for oil-rich seeds like groundnut, soybean, sunflower, and castor.

Respiration test

Principle: The respiration test is based on the principle that vigorous seeds have higher metabolic activity, particularly during the early stages of germination. This increased metabolic rate is reflected in greater oxygen consumption and carbon dioxide evolution, as seeds break down stored carbohydrates and other reserves to support cell division and growth. Measuring the rate of respiration either by monitoring CO_2 released or O_2 consumed will provide an indirect but reliable indication of seed vigour. Vigorous seeds respire actively and consistently, whereas deteriorated or aged seeds exhibit reduced respiration, indicating poor physiological quality.

- ✓ It was expressed as mg O_2 g^{-1} h^{-1} or mg CO_2 g^{-1} h^{-1}.
- ✓ Widely used for crops like maize, wheat, soybean, barley and groundnut.

Glutamic Acid Decarboxylase Activity (GADA) test

Principle: Glutamic acid decarboxylase (GAD) is an enzyme that catalyses the decarboxylation of L-glutamic acid into γ-aminobutyric acid (GABA). GABA is a key signalling molecule that accumulates in plants under stress conditions, including during seed imbibition and germination. In high-vigour seeds, GAD activity is robust, indicating active metabolic pathways and stress mitigation mechan-

isms. By quantifying the amount of GABA produced from glutamate in the presence of GAD, the GADA test provides a biochemical measure of seed metabolic activity and physiological vigour. Higher GAD activity (*i.e.*, more GABA produced) shows higher seed vigour, while reduced activity indicates less vigour.

- ✓ It is expressed as µg GABA produced per g of seed or per ml of enzyme extract (µg g^{-1} or µg ml^{-1}).
- ✓ Widely used in crops like maize, soybean and some vegetable seeds.

DPPH test

Principle: The DPPH (2,2-diphenyl-1-picrylhydrazyl) test is based on the ability of antioxidants present in seeds to scavenge free radicals. DPPH is a stable free radical that exhibits a deep violet colour in solution, with a strong absorbance at 517 nm. When antioxidants from metabolically active, vigorous seeds interact with DPPH, they donate hydrogen atoms or electrons to reduce the DPPH radical to a yellow-coloured non-radical form (diphenylpicrylhydrazine). The degree of decolorization of the DPPH solution is proportional to the antioxidant capacity of the seed extract, which is considered a biochemical indicator of seed vigour. Higher antioxidant activity (more DPPH scavenging) reflects better ability of seeds to resist oxidative stress, indicating higher vigour.

- ✓ It is expressed as percentage (%).
- ✓ Widely used for oilseeds and seeds with valuable antioxidant properties like medicinal and aromatic seeds.

Hydrolytic enzyme test

Principle: The hydrolytic enzyme test is based on the principle that vigorous seeds exhibit higher activity of hydrolytic enzymes, such as amylases, proteases, and lipases, during the early stages of germination. These enzymes play a key role in mobilizing stored food reserves in the seed endosperm or cotyledons to support seedling growth. Among these, α-amylase is particularly important. It catalyzes the hydrolysis of starch into simpler sugars, which are readily used by the growing embryo. The level of enzymatic activity reflects the metabolic potential and hence the vigour of the seed. Seeds with higher hydrolytic enzyme activity generally germinate faster and produce more robust seedlings, indicates high vigour.

- ✓ It was expressed as µg of reducing sugar released per gram of seed per minute (µg g^{-1} m^{-1}).
- ✓ Widely used for crops like cereals and oilseeds.

Conclusion

Seed vigour is one of the important characteristics of quality seed, which will play a crucial role in seed performance and their ability to produce uniform crop stand. Evaluation of the seed vigour through bio-chemical tests has many advantages then the other tests. These includes shorter duration, detects early physiological deterioration and accurate vigour evaluation.

Microgreens: Harnessing Health from this Superfood

Drashti Malaviya, Ishita Pansuriya, Buddhi Sagar Meena and D. M. Vekaria

Abstract

Microgreens young, tender seedlings of vegetables, herbs, and grains have emerged as a potent superfood due to their dense nutritional profile and rapid growth cycle. Harvested within 7-21 days of germination, these miniature greens contain high levels of essential vitamins, minerals, and bioactive compounds. Their vibrant colours, concentrated flavours, and delicate textures have made them popular among chefs and health-conscious consumers alike. Comparative studies reveal that microgreens often surpass their mature counterparts in nutrient density, offering promising approach for combating micronutrient deficiencies and chronic lifestyle diseases like obesity, diabetes, and cardiovascular disorders. Easy to cultivate in both soil and soilless systems, microgreens require minimal inputs and space, making them ideal for urban farming and controlled environments including potential applications in space missions. Despite their benefits, challenges remain in terms of shelf-life extension, microbial safety, and post-harvest handling. Future research must focus on optimizing cultivation techniques, exploring metabolic profiles, and enhancing consumer awareness to fully harness the health potential of microgreens.

Microgreens, a term used for the emerging food product that is developed from various commercial food crops, such as vegetables, grains and herbs, consist of developed cotyledons along with partially expanded true leaves. They are having rich source of nutrients, concentrated flavours, immaculate and tender texture as well as having vibrant colors. In recent years, microgreens are in demand among restaurant chefs and nutritional researchers due to their potent flavours, appealing sensory qualities, functionality, high amount of vitamins, minerals, and other bioactive compounds, such as ascorbic acid, tocopherol, carotenoids, folate, tocotrienols, phylloquinones, anthocyanins, gluconolates, etc. These qualities attracted research attention for use in the field of human health and nutrition. Globally, in the last decade, especially during and post COVID-19 pandemic, society has been awaken for health and taken interest in eating fresh, healthy, and functional foods, such as sprouted seeds and microgreens. In addition to providing valuable nutritional compositions, they also meet consumers' preferences for novelty and palatability. Moreover, they are a very fascinating product for producers as they require least production requirements and reach their maximum consumption

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within a relatively short time frame (Bhaswant *et al*., 2023)

What are Microgreens?

Microgreens are young vegetables (kale, mustard, radishes arugula, broccoli, beetroot, lettuce, *etc*.), on average, harvested between 7 and 21 days from seeding. The size of microgreens is between one and three inches. Microgreens are composed of three parts: a central stem, cotyledon leaf or leaves and a pair of young true leaves. According to the local industry, as early as in the 1980s, chefs in San Francisco, California, began using microgreens. Initially, there were not many varieties offered. Those available included arugula, basil, beets, kale, and cilantro. However, nowadays many companies are providing varieties of microgreens. A study reported that there are 25 microgreens that are commercially, with the potential to add value to new food products (Choe *et al*., 2018).

Sprouts vs. Microgreens vs. Baby Greens vs. Mature Plants: These three micro vegetables are believed to act as functional foods that provide exceptional nutritional elements, thus, imparting health benefits to the consumers. Production time for sprouts is least among these (3-10 days), while it is highest for mature plants. Microgreens take 7-21 days and baby greens take 20-40 days. Difference in root appearance is also important. Sprouts have very tiny roots without root hairs while mature plants have a strong root system. In the case of microgreens and baby greens, roots with root hairs are present though roots of microgreens are smaller. Here, Sprouts do not require any medium or soil while others require soil or some kind of medium to grow. No harvesting is needed for sprouts.

Nutritional Value of Microgreens: Microgreen is an emerging food source, so information about its chemical composition is less explored and documented. It is said that microgreens are largely associated with micro and macro nutrients, such as Fe, Zn, K, Ca, N, P, S, Mn, Se, Mo, and other. Apart from these mineral components, microgreens are rich source of biological phytochemicals, which have an immense potential to improve human health and also aid in improving diseases. The major bioactive compounds, such as ascorbic acid, phylloquinones, tocopherol, carotene, phenolic antioxidants, carotenoids, anthocyanins, glucosinolates and sugar content are reported to be present in the microgreens in larger contents. A comparison of red cabbage's (*Brassica oleracea* L. var. capitata) phytochemical concentrations during the microgreen and adult growth stages showed that the microgreen stage has a high amount of phylloquinone (2.8 g/100 g FW), β-carotene (11.5 mg/100 g FW), and glucoraphanin (4.8 mol g^{-1} DW) compared with matured stage. However, anthocyanins are in higher quantity at the

mature stage compared to the microgreen stage.

Health Benefits of Microgreens: Numerous community-based and experimental studies highlight the significant health benefits of diets rich in plant-derived foods. Such nutrient-dense diets play a crucial role in preventing micronutrient deficiencies-particularly in essential vitamins and minerals and in reducing the impact of chronic diseases like obesity. Chronic metabolic disorders, which develop gradually and persist over time, pose a growing concern in the healthcare sector. Although these conditions may not present immediate threats, they often lead to long-term complications and elevate health risks. Disorders such as obesity, cardio-vascular diseases, neurodegenerative conditions and diabetes have become increasingly prevalent due to rapid lifestyle changes and poor dietary habits. In this context, microgreens-young, tender vegetables packed with concentrated nutrients, minerals, and bioactive phytochemicals have emerged as a valuable dietary addition. Their exceptional nutritional profile and culinary versatility have placed them at the forefront of functional foods aimed at promoting better health and preventing disease.

How to Grow Microgreens?

Depending on the abilities and objectives, these microgreens can be cultivated in any systems of various complexities. Microgreens can be easily cultivated and maintained in small areas. Microgreens can be cultivated in soil or soilless media, inside or outdoors, and under artificial or natural light. Growers may grow microgreens on a small scale within their kitchens or on a larger scale in industrial production systems for profit. The following are some of the basic steps that are required for cultivation of microgreens:

- ✓ Select the seeds that are suitable for microgreen cultivation. Seeds are free of fungicides and other pesticides, and their non-plant matter content should be low. This is particularly important if one intends to grow microgreens of maize, peas, or spinach crops whose seeds are usually plated with fungicide. Some other kinds of microgreens have mucilaginous seeds, which, when submer-ged, create a thick, jelly-like covering that holds moisture. Mucilaginous seeds include basil and cress. Before planting, they need no soaking before sowing.
- ✓ The microgreen seeds need light and nutrition as soon as they sprout to yield the best possible outcome.
- ✓ For the growing of microgreens, a seedling nutrition solution for vegetative growth is usually sufficient. After applying the nutrient solution, enough moisture should be maintained at growth surface during drying period to keep the roots moist between the watering**.**
- ✓ After planting, the microgreens are ready to harvest in 2-3 weeks; depending on variety. Always have a check of the first true leaves as a sign of readiness. Then, with the help of scissors

cut the greens slightly above the soil's surface.

Wash the microgreens properly under running water and dry them with paper towels. One can serve them directly too or add them to main courses, salads, soups, and sandwiches for better culinary purposes. The rest of the microgreens can also be stored in a refrigerator in plastic bags (Pragati Negi, 2024)

Future Scopes and Challenges

Microgreens, being a highly nutritious and rapidly growing plant variety, have gained the attention of researchers in NASA to combat the limited resources of food and psychological requirements of crew members on orbital flights (Kyriacou *et al*., 2016). Cultivating microgreens in space still requires extensive research to fully overcome the challenges of sanitation, water resources, excessive use of seeds, enhancing the shelf life of microgreens, etc. Microgreens have a comparatively shorter shelf life and can be easily grown. Dehydration can help in increasing the shelf life and preserving nutritional content of microgreens. Generating and analysing in-depth experimentation data on the effects of different drying temperatures on microgreens could prove to be beneficial could analyse the loss/gain of bioactive compounds, and activation energy and help to develop sustainable methods to improve the economics of the microgreens production and its marketability. Microgreens possess different health benefits but challenges in production, storage, and consumption need addressing, including optimizing the growth rate and yield of microgreens. Further research is needed to understand the microbial load and develop techniques to prevent food-borne diseases. Exploring the metabolic profiles of various microgreen species is crucial to map their activity. Additionally, improving production technology, pre- and post-harvest techniques, packaging, and shelf-life maintenance are essential. Increasing awareness of the nutritional value, preparation methods, sensory characteristics and palatability of micro-greens will help enhance health outcomes (Singh *et al*., 2024)

Conclusion

Microgreens are nutrient-rich, young vegetable greens harvested within 7-21 days of germination, offering vibrant colors, concentrated flavors and tender textures. They are packed with essential vitamins, minerals and bioactive compounds like carotenoids, glucosinolates and antioxidants, making them a powerful functional food. Compared to sprouts, baby greens and mature plants, microgreens strike a balance between rapid growth and high nutritional value. Their ease of cultivation in small spaces and minimal resource requirements make them attractive to both home growers and commercial producers. With increasing health awareness post-COVID-19, microgreens have gained popularity among chefs and nutritionists. They show promise in combating chronic diseases like obesity and diabetes due to their dense nutrient profile. However, challenges such as short shelf life, microbial safety and post-harvest handling need

further research. Innovations in drying, packaging and cultivation techniques can enhance their marketability and sustainability. Overall, micro-greens represent a promising avenue for improving global nutrition and food security.

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Seed Pelleting: An Integrated Approach for Nutrition, Protection and Growth

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Introduction

Seeds of superior quality is the foundation of agricultural production as it may yield large quantities when planted on fertile terrain. Meanwhile, a lot of crop species generate seeds that are difficult to manage during planting because they are tiny, light or irregularly shaped. Modern seed enhancement methods, of which seed pelleting is a key component, are being used more and more to get around these restrictions. Seed pelleting is the technique of covering or encapsulating seeds with a thin layer of inert substance, just enough to generate globular, homogeneous units that are easy to manage. This advancement makes it possible to use automated planters to precisely deposit seeds, guaranteeing the right depth and spacing in the soil (Singh and Kumar, 2022). As a result, less thinning is required, labour expenses are decreased and the establishment of crops is improved overall. To further improve seed vigour and field performance, the pellets may additionally include growth regulators, micronutrients, microbial inoculants, bio stimulants, and protective compounds (Hussain *et al.*, 2022). Seed pelleting ensures greater establishment, more effective use of resources and increased production by converting irregular seeds into precise units.

Materials for pelleting seeds and their selection criteria: Adhesives and coating/filler materials are the two primary components needed for seed pelleting and their combined use determines the pellet strength, germination and field performance (Lee *et al*., 2020).

Adhesive Materials: The glue employed largely determines the pellet physical integrity since it affects handling, transportation and sowing effectiveness. Some common adhesives include Carboxy Methyl Cellulose (CMC), Gum Arabic, Methyl Cellulose, Gelatin, Casein, Plastic Resins, Polyvinyl Acetate (PVA), Polyurethane, Polyvinyl Alcohol, Dextran, and Polyethylene Oxide. CMC is one of the most extensively utilized of these. Rice, maida, sago and starch gruels (5-10%) are other common traditional low cost binders (Johnson *et al*., 2022).

Coating/Filler Materials: Diatomaceous earth, lime, gypsum, dolomite, rock phosphate, charcoal,

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vermiculite, peat and chicken manure are among the often used fillers. Botanical powders including neem, moringa, tamarind, vitex, pongamia and prosopis (200-300 g kg^{-1} seed) are also employed (Lee *et al*., 2020). The perfect filler should be safe for the rhizosphere and seeds non-toxic, quickly broken down by soil moisture, porous to provide aeration and economical.

Fig. 1: Seed Pelleting with Curry leaf (*Murraya koenigii*) powder

Procedure for seed pelleting: The three fundamental processes are rolling, coating and stamping (Bardhan *et al*., 2021). Stamping entails applying glue on the seeds. Seeds are coated with the filler material, which is then rolled into pellets and allowed to dry in the shade before being packaged, transported and sown (Liu *et al*., 2021).

Different types of Seed Pelleting

Inoculant pelleting: Biofertilizers such as *Rhizobium*, *Azotobacter*, *Azospirillum*, PSB and VAM are used in inoculant pelleting.

Protective pelleting: Using insecticides, fungicides, *Trichoderma*, bird repellents, rodent repellents, or herbicide antidotes such 1,8 Napthalic Anhydride and activated carbon is known as protective pelleting.

Nutrient pelleting: To promote germination and early development, fertilizer pelleting provides micro- and macronutrients (such as $ZnSO_4$, $FeSO_4$, $CuSO_4$, KH_2PO_4, KCl, borax, and DAP) (Hussain *et al.,* 2022).

Hydrophilic pelleting: Utilizing starch graft polymers or magnesium carbonate, hydrophilic pelleting enhances water absorption and aeration.

Oxygen supplier pelleting: Applying calcium or zinc peroxide coating to increase the availability of oxygen, particularly for seeds with hard coatings or on soil that has been wet (Wang *et al.,* 2021).

Types of Pellets

Dissolving/Melt type: It takes more water and time for oxygen to reach the seed since coatings disintegrate when moist.

Split type: When wet, coatings maintain their form, let moisture in, then break apart as the seed grows, facilitating improved oxygen access and quicker germination.

Benefits of pelleting: By permitting singulation, it makes precise planting possible, which is very helpful in automated farming (Garg *et al*., 2020). The procedure improves flow in seed drills, guarantees precise seed placement, and makes handling small or oddly shaped seeds simpler. The accurate dosing of pesticides and nutrients straight into the seed, which reduces waste and increases efficiency, is another important advantage. Additionally, pelleting promotes uniform germination and field establishment and decreases the total seed rate needed while also

making handling simpler by making the seeds larger (Singh and Kumar, 2022).

Technological Advancements in seed pelleting

One of the advancements is the automated pelletizing systems which has resulted in notable breakthroughs in modern pelletizing technology. Advanced controls and sensors are used by automated pelletizing machines to guarantee constant pellet formation and accurate application of pelletizing ingredients (Wang *et al*., 2021) and the other advancement is accurate particle size management that is essential for consistent planting and the best possible seed performance. The utilization of advanced equipment that enables precise control over particle size and form is one example of how pelletizing technology has advanced. During manufacturing, technologies like digital imaging and laser scanning are used to track and modify pellet parameters (Liu *et al*., 2021).

Conclusion

A crucial step in reducing seed rate and thinning techniques during seed production is seed pelleting. Pelleted seeds are easier to sow since they don't become trapped or jammed in automated planters. Seed pelleting facilitates handling during sowing, especially for small-seeded crops like lettuce and carrots that are challenging to handle. Thus, seed pelleting lowers the cost of producing seeds while simultaneously improving their quality.

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Climate-Smart Breeding

Vengatesh M., Nivetha A. L. and Shridevi S.

Climate-Smart Breeding is a transformative approach in plant breeding that aims to develop crop varieties specifically adapted to the challenges and opportunities presented by climate change. It's a critical component of Climate-Smart Agriculture (CSA), which seeks to sustainably increase agricultural productivity and incomes, build resilience to climate change, and reduce greenhouse gas emissions. The traditional goal of plant breeding was often to maximize yield under optimal conditions. However, with unpredictable weather patterns, increased frequency of extreme events (droughts, floods, heat waves), new pest and disease outbreaks, and shifts in growing seasons, crops need to be resilient and adaptable to a wider range of stressful environments. Climate-Smart Breeding integrates modern scientific tools with traditional breeding knowledge to achieve these complex objectives.

Key Objectives of Climate-Smart Breeding

Enhanced Resilience to Abiotic Stresses

Drought Tolerance: Developing varieties that can maintain yield under water scarcity, with improved water-use efficiency (WUE) and deeper root systems.

Heat Tolerance: Breeding crops that can withstand higher temperatures during critical growth stages, preventing yield loss and quality degradation.

Salinity Tolerance: Creating varieties that can grow in saline soils or with saline irrigation water, a growing problem in many coastal and arid regions due to sea-level rise and improper irrigation.

Flooding/Waterlogging Tolerance: Developing crops that can survive and recover from periods of excessive water, particularly important for rice and other crops in flood-prone areas.

Cold Tolerance: For crops expanding into new regions or facing unexpected cold snaps.

Increased Resistance to Biotic Stresses

Climate change can alter the distribution and virulence of pests and diseases. Climate-Smart Breeding aims to develop varieties with broad and durable resistance to these evolving threats, reducing reliance on chemical interventions.

Improved Resource Use Efficiency

Nutrient Use Efficiency (NUE): Breeding crops that can efficiently utilize available nutrients (e.g., nitrogen, phosphorus) from the soil, reducing the need for excessive synthetic fertilizers and mitigating greenhouse gas emissions (e.g., nitrous oxide).

Light Use Efficiency: Especially relevant for contr-

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olled environments, but also important for maximizing photosynthesis under varying light conditions in the field.

Adaptation to Shifting Seasons and Growing Windows: Developing varieties with altered phenology (timing of flowering, maturity) to fit new, shorter, or longer growing seasons, or to escape periods of peak stress. This includes early maturing varieties or those with flexible planting windows.

Maintaining or Enhancing Nutritional Quality: Rising CO_2 levels can sometimes reduce the nutritional content of staple crops. Climate-Smart Breeding aims to maintain or even enhance the nutritional value (e.g., protein, micronutrients) of crops under changing climatic conditions.

Yield Stability in Variable Environments: The goal is not just high yield, but stable yield across a range of environmental conditions, ensuring consistent food production even when the climate is unpredictable.

Techniques and Approaches in Climate-Smart Breeding

Climate-Smart Breeding integrates conventional breeding methods with cutting edge technologies:

Speed Breeding: By manipulating environmental factors (light, temperature, CO_2) in controlled environments (like specialized greenhouses or CEA facilities), breeders can significantly shorten the crop generation cycle, allowing for rapid screening and selection of climate-resilient traits. This accelerates the development of new varieties.

Genomics and Molecular Breeding

Marker-Assisted Selection (MAS): Using DNA markers linked to desired traits (e.g., drought tolerance genes) to select promising plants at an early stage, rather than waiting for them to express the trait in the field. This saves time and resources.

Genomic Selection (GS): A more advanced form of MAS that uses a large number of markers across the entire genome to predict the genetic merit of individuals more accurately, even for complex traits influenced by many genes.

Gene Discovery and Allele Mining: Identifying valuable genes (alleles) from diverse germplasm collections, including wild relatives and landraces, that confer stress tolerance or other desirable climate-smart traits.

Next-Generation Sequencing (NGS) and Pan-genomics: Rapidly sequencing entire genomes of many different varieties to uncover vast genetic diversity and identify genes relevant to climate resilience.

Advanced Phenotyping (Phenomics): Utilizing high-throughput, non-destructive methods to rapidly and accurately measure plant traits. This involves sensors, drones, robotics, and imaging technologies (e.g., multispectral, thermal, 3D imaging) to assess plant health, growth, water status, and stress responses in various environments (field and controlled). This data feeds into breeding decisions.

Envirotyping: Characterizing the environmental conditions of different testing sites with high precision to understand how specific genotypes inte-

ract with specific environments (Genotype x Environment (G x E) interactions).

Genome Editing (CRISPR-Cas9): Provides unprecedented precision to make targeted changes to a plant's DNA. This can be used to introduce or enhance stress tolerance, improve nutrient use efficiency, or modify plant architecture for better adaptation to new climates, often without introducing foreign DNA.

Pre-breeding and Wide Hybridization: Introducing desirable genes from wild relatives or exotic germplasm into elite breeding lines. Wild relatives often possess robust stress tolerance mechanisms that have been lost in modern, high-yielding cultivars.

Artificial Intelligence (AI) and Machine Learning (ML): AI and ML algorithms are increasingly used to analyze massive datasets from genomics, phenomics, and environmental data. They can predict crop performance under future climate scenarios, identify optimal crosses, and accelerate decision-making in breeding programs.

Participatory Breeding: Engaging farmers directly in the breeding process, especially in climate-vulnerable regions. Farmers' local knowledge and preferences for specific traits (e.g., taste, cooking quality, local adaptation) are crucial for developing varieties that will be adopted and make a real impact on the ground.

Challenges in Climate-Smart Breeding

Complexity of Climate Change Impacts: Climate change effects are multifaceted (heat, drought, floods, new pests) and vary regionally, making it challenging to breed for multiple stresses simultaneously.

Genetic Complexity of Traits: Many climate-resilient traits (e.g., drought tolerance) are governed by multiple genes, making them difficult to breed for.

Need for Diverse Germplasm: Accessing and utilizing a wide range of genetic diversity, including wild relatives, is crucial, but gene banks need to be well-maintained and characterized.

Integrating Technologies: Effectively combining conventional breeding with genomics, phenomics, and AI requires interdisciplinary expertise and significant investment.

Rapid Varietal Turnover: The pace of climate change demands faster development and deployment of new varieties, which can be challenging for traditional breeding pipelines.

Farmer Adoption: New climate-resilient varieties must be acceptable to farmers and consumers, offering clear benefits in terms of yield stability, quality, and economic returns.

Policy and Regulatory Frameworks: For advanced breeding technologies like gene editing, clear and supportive regulatory frameworks are essential for commercialization and adoption.

Examples and Initiatives (with focus on India)

Drought-Tolerant Rice: Organizations like the International Rice Research Institute (IRRI) and national agricultural research systems (e.g., ICAR in India) have developed drought-tolerant rice varieties like 'Sahbhagi Dhan' in India, which perform well

under water-scarce conditions.

Submergence-Tolerant Rice (SUB1 gene): Rice varieties carrying the SUB1 gene (e.g., Swarna-Sub1 in India) can withstand complete submergence in water for up to two weeks, a crucial trait for flood-prone regions.

Heat-Tolerant Wheat: Research is ongoing to develop wheat varieties that can tolerate higher temperatures during the critical grain-filling period, especially important for India's wheat belt where temperatures are rising.

Salt-Tolerant Crops: Breeding efforts focus on developing rice and other crops that can grow in saline soils, addressing the increasing threat of salinization.

ICAR's National Innovations in Climate Resilient Agriculture (NICRA): In India, ICAR (Indian Council of Agricultural Research) has a flagship program called NICRA, which focuses on strategic research, technology demonstration, and capacity building for climate-resilient agriculture, including climate-smart breeding. They identify and develop stress-tolerant varieties suitable for various agro-climatic zones.

CGIAR Initiatives: International agricultural research centers under CGIAR (e.g., CIMMYT for maize and wheat, ICRISAT for dryland crops) are at the forefront of climate-smart breeding, developing resilient varieties that are disseminated globally, including in India.

Millets: Promoting and breeding improved varieties of millets (like sorghum, pearl millet, finger millet) is a key climate-smart strategy, as these crops are inherently more resilient to drought and heat compared to staple cereals like rice and wheat.

Conclusion

Climate-Smart Breeding is not just about adapting to climate change; it's about proactively shaping the future of agriculture to ensure food and nutritional security for a growing global population in a rapidly changing climate. It requires continuous innovation, collaborative efforts across disciplines and institutions, and a strong commitment to deploying these resilient varieties to farmers worldwide.

Role of Tilling in Crop Improvement

Shridevi S., Vengatesh M. and Nivetha A. L.

Plant breeding aims to develop new crop varieties with improved traits that meet the growing demands for food, feed, fiber, and fuel, especially in the face of climate change and increasing population. TILLING (Targeting Induced Local Lesions IN Genomes) plays a crucial and versatile role in this process by enabling the precise and efficient discovery of new genetic variations.

TILLING role in crop improvement

Creation of Novel Genetic Variation in Elite Germplasm: TILLING starts with chemical mutagenesis (typically using EMS) of an already high-performing or "elite" crop variety. This is a significant advantage because it directly introduces new mutations into a desirable genetic background, avoiding the need for lengthy backcrossing to eliminate undesirable traits (linkage drag) that might come from crossing with wild relatives or landraces. These induced mutations provide a vast pool of genetic diversity that might not exist naturally or be easily accessible through traditional breeding methods.

Targeted Discovery of Desirable Alleles (Gene Variants): Unlike traditional mutagenesis screening which involves visually sifting through millions of plants for a desired phenotype, TILLING is a "reverse genetics" approach. This means breeders start with a known gene sequence and then search for mutations within that specific gene. If a gene is known to control a particular trait (e.g., disease resistance, herbicide tolerance, nutrient content, plant height), TILLING can be used to specifically identify plants that carry mutations in that gene. These mutations can then lead to new alleles (versions) of the gene, some of which might confer beneficial traits.

Functional Genomics and Gene Validation: Before a gene can be targeted for improvement, its function needs to be understood. TILLING is an excellent tool for functional genomics. By identifying individuals with different mutations (an "allelic series" from missense to null mutations) within a gene, researchers can study how those mutations affect the gene's function and the resulting plant phenotype. This helps to validate the role of a specific gene in controlling a particular trait, providing clear targets for further breeding efforts.

Enhancing Specific Traits

Disease Resistance: TILLING has been used to identify mutations in genes that make plants susceptible to certain diseases. By disrupting these genes, breeders can create varieties with enhanced

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resistance to pathogens (e.g., powdery mildew resistance in barley, viral resistance in crops).

Abiotic Stress Tolerance: Genes involved in plant response to stresses like drought, salinity, heat, or cold can be targeted. TILLING can discover mutations that improve a plant's ability to cope with these environmental challenges, leading to more resilient crops in a changing climate.

Improved Quality Traits

Nutrient Content (Biofortification): Mutations can be sought in genes involved in the uptake, transport, or storage of essential minerals (e.g., iron, zinc) or vitamins. For example, TILLING has been used to increase provitamin A in rice.

Reduced Anti-nutritional Factors: Some crops contain compounds that reduce nutrient availability or are toxic (e.g., phytate in cereals, cyanogenic glycosides in cassava). TILLING can identify mutations that lower these harmful compounds.

Improved Processing Qualities: Traits like starch composition in grains (e.g., high amylose or waxy starch) or oil content in oilseeds can be modified.

Agronomic Traits: TILLING can alter plant architecture (e.g., dwarfism for lodging resistance), flowering time (for adaptation to different growing seasons), or improve yield components (e.g., seed size, number of grains).

Non-Transgenic and Regulatory Advantage: A significant advantage of TILLING is that it introduces mutations through a natural-like process (chemical mutagenesis) without incorporating foreign DNA. Therefore, the resulting varieties are generally considered non-GMO (Genetically Modified Organism) in most regulatory frameworks worldwide. This bypasses the strict and often lengthy regulatory approval processes associated with transgenic crops, accelerating the time to market for new varieties. This makes TILLING a highly attractive option for both public and private breeding programs.

Applicability to Diverse Crop Species: Unlike some other genetic modification techniques (like transformation) which can be challenging for certain recalcitrant species, TILLING can be applied to almost any plant species that can be chemically mutagenized and for which some sequence information is available. This includes important polyploid crops (like wheat, potato, sugarcane) which are often difficult to genetically engineer.

Cost-Effectiveness and Efficiency: While establishing a TILLING platform requires initial investment, once established, it can be a relatively cost-effective and high-throughput method for discovering new alleles compared to traditional forward genetics screens or large-scale re-sequencing of entire mutant populations. The pooling of DNA samples significantly reduces screening costs.

Examples of TILLING in Crop Improvement

Wheat: Development of varieties with altered starch composition (e.g., waxy wheat) or improved baking quality.

Barley: Identification of genes related to disease resistance (e.g., powdery mildew) and malting quality.

Rice: Improvement of grain quality, nutrient content, and stress tolerance.

Maize: Enhancing protein quality, herbicide resistance, and flowering time.

Tomato: Identifying mutations in genes that control fruit ripening, size, or disease resistance.

Soybean: Developing varieties with altered oil profiles or improved yield.

Conclusion

TILLING serves as a bridge between classical mutagenesis and modern genomics. It effectively harnesses the power of random mutation induction and combines it with precise molecular screening to rapidly identify beneficial genetic variations in targeted genes within elite germplasm. This makes TILLING an indispensable tool in modern crop breeding for developing improved, resilient, and nutritious crop varieties to address global food security challenges.

Digital Breeding and Artificial Intelligence in Crop Improvement

Nivetha A. L., Vengatesh M. and Shridevi S.

The global population is steadily increasing, demanding higher agricultural productivity from a finite and often diminishing arable land base. Concurrently, climate change introduces unprecedented challenges through altered weather patterns, increased prevalence of pests and diseases, and greater abiotic stresses. In this context, traditional plant breeding methods, while historically successful, are often too slow and resource-intensive to keep pace with these evolving demands. This has spurred a revolutionary shift towards "digital breeding," a paradigm that integrates advanced technologies like genomics, bioinformatics, and data analytics. Central to this transformation is the escalating role of Artificial Intelligence (AI) and its subfields like Machine Learning (ML) and Deep Learning (DL), which are fundamentally reshaping how we understand, predict, and manipulate plant genetics for accelerated crop improvement.

Digital Breeding: A Data-Driven Revolution

Digital breeding represents the modernization of conventional plant breeding by leveraging digital tools and data-driven approaches across every stage of the breeding pipeline. Traditionally, plant breeding involved meticulous selection of parent plants, crossing them, and then evaluating progeny over multiple generations and diverse environments a process that could span a decade or more for a single new variety. Digital breeding aims to shorten these cycles, enhance precision, and improve the effectiveness of selection by minimizing human intervention and maximizing the use of vast datasets. At its core, digital breeding relies on two key technological advancements:

High-Throughput Genotyping: This involves rapidly and cost-effectively analyzing the genetic makeup (genotype) of a large number of plants. Techniques like Next-Generation Sequencing (NGS) generate massive amounts of genomic data, providing detailed insights into the genetic variations within plant populations. This data is crucial for identifying specific genes or markers associated with desirable traits.

High-Throughput Phenotyping: This refers to the automated and rapid measurement of physical characteristics (phenotypes) of plants, such as growth rate, yield components, disease resistance, and stress tolerance. Technologies like drones, robotic systems, and advanced imaging (e.g., RGB, thermal, multispectral) equipped with various sensors can capture extensive phenotypic data in real-time or near real-time, often in diverse field or

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controlled environments. This non-destructive assessment allows for continuous monitoring and a deeper understanding of how genotypes translate into phenotypes under varying conditions. The integration of these "omics" technologies (genomics, phenomics, transcript-mics, etc.) generates "big data" in plant breeding. This deluge of information necessitates sophisticated computational tools for management, analysis, and interpretation, which is precisely where AI comes into play.

The Power of AI in Crop Improvement

Artificial Intelligence, particularly Machine Learning and Deep Learning, acts as the computational engine driving the digital breeding revolution. AI algorithms can process, learn from, and make predictions based on complex, multi-dimensional datasets that would be impossible for humans to analyze efficiently. Its applications span the entire crop improvement pipeline, from foundational research to the release of new varieties and even farm management.

Key Applications of AI in Crop Improvement

Genomic Selection and Marker-Assisted Breeding

Genomic Selection (GS): AI, especially ML algorithms, is instrumental in genomic selection. Instead of relying on phenotypic evaluation over multiple seasons, GS uses genome-wide molecular markers to predict the breeding value of individuals. ML models (e.g., Ridge Regression, LASSO, Elastic Net) are trained on a "training population" with known genotypes and phenotypes to build prediction models. These models can then estimate the genetic merit of "candidate" individuals based solely on their genomic data, even before they are phenotyped. This significantly accelerates breeding cycles by allowing for earlier and more accurate selection of promising lines.

Marker-Assisted Selection (MAS): While GS uses all markers, MAS focuses on specific genetic markers linked to particular traits (e.g., disease resistance genes). AI algorithms can help identify these strong marker-trait associations more efficiently from large genomic datasets, enabling breeders to select for desired traits with high precision.

Gene Editing and Functional Genomics: AI can predict the effects of specific gene edits using technologies like CRISPR-Cas9, guiding targeted modifications to plant DNA. This allows for precise engineering of desired traits without introducing foreign genes, offering a faster and more publicly acceptable route to crop improvement. AI also assists in analyzing functional genomics data to understand how genes express and interact, further enhancing our ability to manipulate plant characteristics.

High-Throughput Phenotyping and Image Analysis

AI-powered computer vision and image recognition systems are transforming phenotyping. Drones, ground robots, and stationary cameras capture vast amounts of imagery of crops in fields or controlled environments.

Trait Quantification: AI algorithms analyze these

images to automatically quantify complex plant traits such as plant height, leaf area, biomass, canopy cover, flowering time, and root architecture, which are laborious and prone to human error when measured manually.

Stress Detection: AI can detect subtle signs of plant stress (e.g., nutrient deficiencies, drought, heat, salinity) or disease much earlier than the human eye, often before visible symptoms appear. By analyzing changes in color, texture, or temperature captured by various sensors, AI can pinpoint problematic areas, enabling timely intervention and more precise application of inputs.

Yield Prediction and Environmental Optimization

AI models can integrate diverse datasets, including genomic information, phenotypic data from various growth stages, environmental parameters (weather, soil conditions), and historical yield records, to build highly accurate yield prediction models. This allows breeders and farmers to anticipate harvest outcomes and make informed decisions.

Precision Agriculture: AI is central to precision agriculture, optimizing resource allocation. By analyzing real-time data from sensors (soil moisture, nutrient levels), drones, and satellites, AI provides insights into the specific needs of different areas within a field. This enables variable rate application of water, fertilizers, and pesticides, reducing waste, lowering costs, and minimizing environmental impact.

Disease and Pest Management

AI-driven systems can identify plant diseases and pest infestations early and accurately through image analysis of leaves, stems, or whole plants. This early detection allows for targeted application of treatments, reducing the spread of pathogens and the overall use of chemicals.

Predictive Modeling: AI can predict the likelihood of disease outbreaks or pest attacks based on environmental conditions and historical data, allowing for proactive preventive measures.

Accelerated Breeding Cycles

By streamlining data collection, analysis, and decision-making, AI significantly shortens breeding cycles. The ability to predict performance from genomic data and accurately phenotype in high throughput means fewer generations are needed for selection, bringing improved varieties to market much faster.

Optimized Crosses: AI algorithms can analyze genetic data to suggest the most promising parental crosses, maximizing the chances of creating offspring with desired trait combinations. This reduces the number of crosses needed and increases the efficiency of the breeding program.

Conclusion

Digital breeding, supercharged by Artificial Intelligence, is not merely an incremental improvement but a transformative shift in crop improvement. It empowers breeders to navigate the immense complexity of plant genetics and environmental interactions with unprecedented precision and speed.

By integrating high-throughput genotyping and phenotyping with advanced AI algorithms for data analysis, prediction, and decision-making, we are entering an era of "smart breeding." This synergy is crucial for developing climate-resilient, high-yielding, and nutritious crop varieties that are essential for ensuring global food security in the face of a growing population and changing environmental conditions. As AI technologies continue to advance, their integration into plant breeding will only deepen, leading to even more efficient and sustainable agricultural practices.

From Waste to Wealth: Pomegranate Peel Rich Source of Bioactive Compounds and Functional Food Ingredients

Sakshi Soni and Preeti Chaudhary

Introduction

Pomegranate (*Punica granatum* L.) is one of the oldest known fruit crops, known for its symbolic, cultural, nutritional and medicinal value since ancient times yet modern scientific exploration has further revealed that the peel which constitutes nearly 40-50% of the fruit by weight is often discarded as waste despite being a concentrated reservoir of bioactive compounds with remarkable potential for health promotion and application as functional food ingredients. The peel waste of pomegranate is a treasure of polyphenols, flavonoids, ellagitannins, tannins, organic acids, alkaloids, minerals and dietary fibers that possess superior antioxidant, anti-inflammatory, antimicrobial, anti-cancer and cardioprotective properties compared to the edible arils. The rediscovery of peel's medicinal importance has been driven by the global trend toward sustainable utilization of agricultural by-products and the rising consumer demand for natural, eco-friendly and functional food ingredients. Valorization of pomegranate peel not only addresses environmental challenges associated with waste disposal but also offers economic opportunities for the food, pharmaceutical, cosmetic, agricultural and environmental sectors. Its applications range from being incorporated in functional foods and nutraceuticals, to serving as a natural preservative, to being used in drug delivery systems, animal feed, bioplastics and even wastewater treatment. Thus, studying the nutritional and medicinal effects of pomegranate peel along with its wide-ranging functional food applications provides a holistic perspective on how an undervalued by-product can transform into a high-value resource that bridges human health, sustainability and circular economy models.

Nutritional Composition of Pomegranate Peel:

The nutritional richness of pomegranate peel lies in its dense concentration of phytochemicals and essential nutrients making it far more potent in bioactive compounds than the edible pulp and this explains why it is increasingly being considered a functional food ingredient rather than just an agro-residue. Chemically, the peel is exceptionally high in polyphenols, particularly hydrolyzable tannins such as punicalagin, punicalin, ellagic acid and gallic acid, which are responsible for its intense antioxidant capacity in fact, scientific studies demonstrate that the antioxidant activity of peel extracts surpasses that of red wine, green tea and many commonly consumed superfoods. It also contains abundant flavonoids like catechins, quercetin and anthocyanins which synergize with tannins to neutralize

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free radicals, inhibit lipid peroxidation and protect cellular integrity. Dietary fiber forms another major nutritional component of the peel, with insoluble fibers like cellulose, lignin and hemicellulose contributing to improved gut health, satiety and cholesterol management while soluble fibers aid in stabilizing blood glucose and enhancing the bioavailability of minerals. From a mineral perspective, the peel is rich in potassium, calcium, magnesium, sodium, iron and zinc, elements that support cardiovascular health, bone density, enzymatic activity and immune function. Organic acids, particularly citric acid, malic acid and ascorbic acid, further contribute to peel's antimicrobial properties and nutritional quality. Moreover, proteins and trace amino acids have also been reported, adding to its nutraceutical profile. The compositional variability of the peel depends on cultivar, growing conditions and processing methods, but overall, its phytochemical density positions it as a superior source of antioxidants compared to the edible fraction. Importantly, the synergy between peel constituents enhances their effectiveness, as punicalagin not only acts as a direct antioxidant but also facilitates the regeneration of other antioxidants such as vitamin C and E. This dense nutritional matrix has driven the incorporation of peel powder and extracts into various functional foods, beverages and supplements allowing consumers to derive concentrated benefits without consuming large amounts of fruit. By unlocking the nutritional potential of peel, researchers have provided a sustainable alternative for addressing dietary deficiencies and combating oxidative stress-related disorders.

Table 1: Nutritional Composition of Pomegranate Peel

Component	Approximate Value (per 100 g DW)
Total phenolics	2,500-6,000 mg GAE
Punicalagin	1,500-2,000 mg
Ellagic acid	250-500 mg
Flavonoids (catechin, quercetin,anthocyanins)	150-350 mg
Dietary fiber (total)	40-45 g (Insoluble: 30-35 g; Soluble: 10-12 g)
Proteins	4-7 g
Lipids	1-2 g
Minerals	K: 800-900 mg; Ca: 150-200 mg; Mg: 60-80 mg; Na: 40-50 mg; Fe: 4-6 mg; Zn: 1-2 mg
Organic acids	Citric acid: 1.2-1.8 g; Malic acid: 0.5-1.0 g; Ascorbic acid (Vit. C): 20-30 mg

Medicinal Effects of Pomegranate Peel

The medicinal value of pomegranate peel is attributed to its extraordinary spectrum of pharmacological effects which include antioxidant, anti-inflammatory, antimicrobial, anticancer, anti-diabetic, anti-obesity, hepatoprotective, cardioprotective and even neuroprotective activities making it one of the most versatile natural remedies supported by both traditional use and modern clinical validation.

Antioxidant Properties: Pomegranate peel exhibits exceptionally high antioxidant activity, primarily attributed to hydrolyzable tannins (punicalagin, punicalin), flavonoids (quercetin, catechin) and phenolic acids (gallic acid, ellagic acid). These compounds function as electron donors, neutralizing reactive oxygen species (ROS) such as superoxide anions (O_2^-), hydroxyl radicals (-OH) and hydrogen peroxide (H_2O_2). By reducing oxidative stress, peel-

derived antioxidants inhibit lipid peroxidation, protect DNA from oxidative damage and enhance endogenous defense mechanisms (e.g., superoxide dismutase, catalase and glutathione peroxidase). This activity is particularly significant in the prevention of atherosclerosis, neurodegeneration and carcino-genesis.

Fig. 1: Medicinal value of pomegranate peel

Antimicrobial Activity: The antimicrobial effect of pomegranate peel is mediated by tannins and phenolic acids, which disrupt microbial cell membranes, increase membrane permeability and cause leakage of cellular contents. Punicalagin and ellagic acid exhibit strong bacteriostatic and fungistatic effects against *Escherichia coli*, *Staphylococcus aureus*, *Listeria monocytogenes* and *Candida albicans*. The mechanism involves inhibition of microbial enzymes such as DNA gyrase and alteration of quorum-sensing pathways, thereby reducing bacterial virulence. This property has implications for food preservation and development of plant-based antimicrobial agents.

Anti-inflammatory Effects: Chronic inflammation is associated with overproduction of pro-inflam-matory cytokines such as TNF-α, IL-6 and IL-1β and activation of transcription factors like NF-κB. Pomegranate peel polyphenols modulate these signaling pathways by downregulating NF-κB activation and suppressing cyclooxygenase-2 (COX-2) and inducible nitric oxide synthase (iNOS) expression. This results in decreased synthesis of prostaglandins and nitric oxide, reducing tissue inflammation. Experimental studies also show that peel extracts attenuate edema, inflammatory cell infiltration and oxidative damage in animal models of arthritis and colitis.

Anti-cancer Potential: Bioactive compounds in pomegranate peel exert anti-proliferative and pro-apoptotic effects on cancer cells. Ellagic acid and punicalagin induce intrinsic apoptosis by activating caspase-3 and caspase-9, increasing Bax/Bcl-2 ratio and triggering mitochondrial cytochrome c release. Additionally, these compounds arrest the cell cycle at the G0/G1 or G2/M phase, thereby inhibiting tumor growth. Pomegranate peel polyphenols also inhibit angiogenesis by downregulating vascular endothelial growth factor (VEGF) expression. In vitro studies have demonstrated growth inhibition of breast, colon and prostate cancer cell lines, highlighting the peel's chemopreventive potential.

Anti-diabetic Effects: Pomegranate peel extract exhibits hypoglycemic effects through multiple mechanisms such as inhibition of carbohydrate-digesting enzymes (α-amylase and α-glucosidase), leading to delayed glucose absorption. Enhancement of pancreatic β-cell function and protection against oxidative stress-induced apoptosis. Improvement of insulin sensitivity via modulation of peroxisome proliferator-activated receptor gamma (PPAR-γ)

signaling. Animal studies indicate that administration of peel extract lowers fasting blood glucose, improves glucose tolerance and reduces glycated hemoglobin (HbA1c) levels.

Cardioprotective Effects: Cardioprotective activity of pomegranate peel is attributed to its ability to reduce low-density lipoprotein (LDL) oxidation, improve endothelial nitric oxide (NO) availability and suppress vascular inflammation. Polyphenols in the peel prevent foam cell formation and plaque progression by downregulating scavenger receptors on macrophages. Clinical studies have shown that supplementation with pomegranate peel extract improves lipid profile by lowering total cholesterol and triglycerides while increasing high-density lipoprotein (HDL). Additionally, its antioxidant action prevents myocardial damage induced by ischemia-reperfusion injury.

Functional Food Applications of Pomegranate Peel: Beyond its nutritional and medicinal effects, pomegranate peel is increasingly being recognized for its versatility as functional food ingredient across multiple industries, transforming it from waste into a sustainable resource that contributes to health, economy and environmental protection. In the food industry, peel powder and its extracts are widely explored as functional ingredients in bakery products, dairy items, meat preservation and beverages, where they enhance antioxidant content, improve shelf life and deliver health-promoting compounds, herbal teas made from pomegranate peel blended with other botanicals are gaining popularity as detoxifying, digestive and antioxidant-rich drinks. As a natural preservative, peel extracts inhibit microbial growth and lipid oxidation in perishable foods, offering a safer alternative to synthetic additives. In pharmaceuticals, peel-derived bioactives are being developed into nutraceutical supplements, oral health formulations such as toothpastes and mouthwashes and drug delivery systems using peel polysaccharides as excipients. The cosmetic industry has also adopted peel extracts for anti-aging creams, UV-protective lotions and haircare formulations, owing to their collagen-boosting, melanin-regulating and antimicrobial effects. In agriculture, dried peel powder serves as a livestock feed additive, improving gut health, immunity and productivity in poultry and ruminants, while in soil management, peel-derived compost enhances fertility and microbial diversity. Peel extracts are also being tested as biopesticides and natural antifungals for crop protection. Environmental and industrial applications are equally promising: peel-based activated carbon and biochar are effective adsorbents for removing heavy metals, dyes and toxins from wastewater; peel-derived biopolymers and pectin are being developed into biodegradable films and coatings for sustainable packaging; and peel biomass can be utilized for bioethanol and biogas production, contributing to renewable energy solutions. In nanotechnology, peel extracts have been employed as green reducing agents in the synthesis of silver and gold nanoparticles, opening avenues for eco-friendly nano-

Table 2: Food Products Developed from Pomegranate Peel

Food Product	Formulation	Functional Benefit
Bakery Products (Bread, Biscuits, Cookies, Cakes)	Peel → washed → shade dried / oven dried → ground to fine powder → incorporated (1–10%) into wheat flour dough/batter → baked	Increases dietary fiber, antioxidant activity, reduces lipid oxidation, enhances shelf life
Dairy Products (Yogurt, Cheese, Ice cream)	Peel → extracted with water/ethanol → filtered & concentrated → added to milk (0.5–2%) before fermentation (yogurt/cheese) or during mix preparation (ice cream)	Improves phenolic content, enhances probiotic viability, antioxidant activity, antimicrobial effect
Functional Beverages (Juices, Smoothies, Herbal Tea)	Peel → dried & powdered OR aqueous/ethanolic extract → spray-dried → added to juice/tea formulations (0.1–1%)	Increases antioxidant capacity, provides antimicrobial effect, improves nutraceutical value
Meat & Fish Products (Cutlets, Fillets, Sausages)	Peel → ethanolic/methanolic extract → applied as dip, marinade, or incorporated into minced products → stored at refrigeration	Acts as natural preservative, inhibits lipid peroxidation, reduces microbial spoilage, extends shelf life
Edible Films & Biodegradable Packaging	Peel polyphenolic extract → incorporated into biopolymer solution (gelatin, chitosan, starch) → cast into films → dried	Antimicrobial, antioxidant packaging, eco-friendly alternative to synthetics
Jam & Jelly Fortification	Peel powder/extract added (1–2%) during boiling stage of jam/jelly preparation	Enhances antioxidant activity, adds natural color, increases stability
Snacks (Extruded, Bars, Chips)	Peel powder (2–5%) incorporated into cereal mixes, snack bars, or extruded products	Increases fiber and phenolic content, improves antioxidant potential
Fermented Products (Kombucha, Kefir, Vinegar)	Peel extract added to fermentation media → fermented with microbes (yeast, bacteria)	Boosts polyphenolic content, enhances bioactive potential, adds antimicrobial effects

materials with applications in medicine, catalysis and electronics. These diverse applications reflect the peel's role as a bridge between waste valorization and sustainable innovation, demonstrating how one agricultural by-product can add value across sectors while reducing environmental burden.

Conclusion

The exploration of pomegranate peel reveals it as an extraordinary resource that transcends its identity as a fruit by-product, offering dense nutrition, powerful medicinal effects and wide-ranging applications that align with the goals of health promotion, waste valorization and sustainable development. Its composition, rich in polyphenols, tannins, flavonoids, dietary fibers and minerals, underpins its remarkable antioxidant, anti-inflammatory, antimicrobial, anticancer, antidiabetic, cardioprotective and hepatoprotective activities, making it a multifunctional candidate for future nutraceuticals and therapeutics. The transformation of peel into value-added products across food, pharmaceuticals, cosmetics, agriculture and environmental sectors not only enhances economic opportunities but also addresses pressing challenges of waste management and ecological sustainability. However, to fully harness its potential, future research must address variability in composition, standardize extraction and processing methods, improve sensory acceptability in food applications and conduct large-scale clinical studies to validate health benefits. Integration of advanced technologies such as nanotechnology, encapsulation and bioengineering can further enhance the functionality and bioavailability of peel-derived compounds. Policy frameworks, industry collaborations and consumer education will also play pivotal roles in accelerating adoption.

Ultimately, pomegranate peel represents more than a source of nutrition or medicine-it symbolizes a paradigm shift toward circular economy models where agricultural residues are no longer waste but vital resources that support human health, sustainable industries and environmental resilience. The future lies in scaling innovations from laboratories to markets and ensuring that the benefits of this ancient fruit's peel reach communities worldwide, thereby transforming an overlooked waste into a cornerstone of sustainable health and development.

Certification and Marketing of Organic Horticultural Produce

Tikam Das Vaishnav and Aakanksha Tiwari

Abstract

Organic horticulture has gained global importance as consumers increasingly demand safe, chemical-free, and environmentally sustainable food. Certification and marketing serve as two crucial pillars for ensuring the credibility and commercial success of organic horticultural produce. Certification provides authenticity by verifying compliance with established organic standards, thereby safeguarding consumers from false claims and enabling producers to access premium domestic and international markets. Marketing strategies, including direct sales, online platforms, cooperatives, and export channels, play a vital role in connecting certified farmers with health-conscious and eco-friendly consumers. Despite significant opportunities, challenges such as high certification costs, complex documentation, weak supply chains, and limited consumer awareness constrain the growth of this sector. Strengthening farmer cooperatives, promoting low-cost certification systems like PGS-India, enhancing digital traceability, and expanding cold chain infrastructure can bridge these gaps. With integrated policy support, consumer education, and innovative marketing, certified organic horticultural produce can ensure profitability for farmers, trust for consumers, and sustainability for the agricultural system.

Introduction

Organic horticulture has emerged as a vital component of sustainable agriculture, responding to growing consumer concerns about food safety, environmental degradation and health consciousness. Unlike conventional farming systems that rely heavily on synthetic fertilizers and pesticides, organic horticulture emphasizes ecological balance, biodiversity, and soil health through the use of natural inputs, crop rotation, composting, biofertilizers and biopesticides. However, the success of organic farming goes beyond production practices. For organic produce to reach consumers with trust and authenticity, certification is indispensable. Certification acts as an assurance mechanism, verifying that products adhere to established organic standards and preventing misleading claims in the market. Alongside certification, effective marketing plays a crucial role in ensuring that organic produce not only gains consumer acceptance but also provides fair and profitable returns to farmers. With the rise in health-conscious and eco-friendly consumer preferences, certified organic horticultural produce has immense potential both domestically and globally. This paper explores the processes, challenges and strategies associated with certification and marketing of organic horticultural produce.

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Organic Certification: Concept and Importance

Organic certification is a formal process through which an accredited certification agency verifies that the production, processing, and handling of horticultural produce comply with established organic standards. It ensures transparency, builds consumer confidence, and provides producers with access to premium and export markets.

Objectives of Certification

- ✓ To ensure that horticultural produce is cultivated without the use of synthetic fertilizers, pesticides, or growth regulators.
- ✓ To provide assurance of food safety, nutritional quality, and environmental sustainability.
- ✓ To facilitate both domestic and international trade by meeting globally accepted standards.
- ✓ To safeguard consumers against misleading or false organic claims.

Certification Standards

International Standards

IFOAM: International Federation of Organic Agriculture Movements (global principles and framework).

USDA Organic (United States): Strict regulations for organic production and labeling.

EU Organic Regulations: European Union guidelines for organic agriculture and imports.

Indian Standards

NPOP (National Programme for Organic Production): Overseen by APEDA, covering production, certification, and labeling.

PGS-India (Participatory Guarantee System): A low-cost, community-based certification system suitable for small and marginal farmers.

Certification Process in Organic Horticulture

The certification process ensures that horticultural produce adheres to prescribed organic standards from production to marketing. It involves several sequential steps, each designed to verify compliance and maintain transparency.

Steps in the Certification Process

Application and Registration: Farmers, farmer groups, or producer organizations submit an application to an accredited certification agency along with required details.

Documentation: Proper records of cropping history, input usage, and an organic conversion plan (usually 2-3 years) are maintained.

Inspection: On-site visits by trained inspectors are conducted to evaluate field practices, input sources, and storage facilities.

Residue Analysis: Samples of soil, water, and produce are tested to detect the presence of chemical residues, if any.

Certification Approval: If compliance is established, the certification body issues an organic certificate to the producer.

Labeling and Logo Use: Certified producers can use logos such as India Organic or Jaivik Bharat on their packaging to assure consumers of authenticity.

Marketing of Organic Horticultural Produce

Marketing is a critical component of organic horticulture, as it determines profitability, accessibility, and long-term sustainability of the system.

Organic produce is valued for being pesticide-free, nutrient-rich, and eco-friendly, which enables farmers to command premium prices compared to conventional produce. However, the success of marketing depends on strong supply chains, certification, consumer awareness, and effective branding.

Key Marketing Channels

Direct Marketing

Farmers' Markets: Farmers directly sell fruits, vegetables, and flowers to consumers, eliminating middlemen.

Community-Supported Agriculture (CSA): Consumers pre-pay for seasonal produce, ensuring assured income for farmers.

Farm-Gate Sales: Local buyers visit farms to purchase directly, reducing transportation costs. Example: In states like Kerala and Maharashtra, local organic fairs have become popular platforms for organic vegetables and spices.

Online Platforms

- ✓ E-commerce has revolutionized organic marketing by linking producers to urban consumers.
- ✓ Portals like BigBasket, Amazon Fresh, Nature's Basket, and Flipkart Grocery list certified organic horticultural produce.
- ✓ Specialized apps and websites (*Farm2Kitchen, Organic India, 24 Mantra Organic*) focus exclusively on organic markets.
- ✓ Social media (Facebook, Instagram) is also being used by small farmers to promote and sell directly to consumers.

Cooperatives and Farmer Producer Organizations (FPOs)

- ✓ Cooperatives/FPOs pool together produce from multiple farmers to ensure consistent supply and reduce costs.
- ✓ They negotiate better prices, organize transport, and arrange certification collectively.
- ✓ Example: Sahyadri Farms (Maharashtra) has successfully marketed organic grapes and pomegranates to both domestic and export markets.

Export Markets

- ✓ India is a major exporter of organic spices, tea, coffee, fruits, and medicinal plants.
- ✓ Export destinations include the USA, European Union, Canada, and Middle East.
- ✓ Premium fruits such as organic mangoes, bananas, and pomegranates fetch 20-30% higher prices in global markets.
- ✓ Export is regulated under the NPOP (National Programme for Organic Production) guidelines and requires certification from accredited agencies.

Consumer Preferences

- ✓ Consumers of organic horticultural produce are mostly urban, educated, and health-conscious.
- ✓ They are willing to pay 20-50% higher prices for certified organic fruits and vegetables.
- ✓ Buying decisions are influenced by:
  - Trust in certification logos (India Organic, Jaivik Bharat, USDA Organic, EU Organic).
  - Transparency and traceability of the supply

chain (farm-to-fork approach).

- Perceived health benefits such as reduced chemical residues and higher nutritional content.
- Eco-consciousness many consumers prefer organic to support sustainable agriculture.

Challenges in Marketing

Price Volatility: Premium prices are not always assured due to fluctuating demand.

Supply Chain Gaps: Lack of cold storage and logistics affects perishable horticultural produce.

Consumer Awareness: Many buyers cannot differentiate between certified and uncertified organic products.

Market Exploitation: Middlemen sometimes label conventional produce as "organic" to fetch higher prices.

Strategies for Improvement

- ✓ Strengthening Farmer-Consumer Linkages through mobile apps and urban organic retail outlets.
- ✓ Branding and Packaging-attractive, eco-friendly packaging helps build consumer trust.
- ✓ Government Support-schemes like PKVY (Paramparagat Krishi Vikas Yojana) promote organic clusters.
- ✓ Promotion of Farmers' Cooperatives to handle certification, storage, and collective marketing.
- ✓ Use of Technology-Blockchain and QR codes for traceability of organic produce.

Challenges in Certification and Marketing

Although organic horticulture offers significant opportunities, several barriers hinder the widespread adoption of certification and efficient marketing systems. These challenges affect both farmers and consumers, creating gaps between production and market realization.

Key Challenges

High Cost of Certification: Obtaining organic certification involves inspection fees, laboratory analysis, and annual renewal costs. For small and marginal farmers, these expenses are often unaffordable, making them dependent on government subsidies or farmer cooperatives.

Complex Documentation: Certification requires strict record-keeping of all inputs, cropping history, and conversion plans for 2-3 years. Many farmers lack training or literacy support to maintain such detailed documentation, which discourages adoption.

Market Exploitation: In the absence of strong farmer organizations, middlemen and traders often capture most of the profits. Farmers receive only a small share of the premium price, reducing the economic incentive to grow organic produce.

Lack of Consumer Awareness: Many consumers cannot differentiate between certified organic and conventionally grown produce. Limited awareness of certification logos such as *India Organic* or *Jaivik Bharat* reduces consumer trust, allowing uncertified products to be misrepresented as "organic."

Supply Chain Gaps: Perishable horticultural crops like fruits and vegetables require efficient cold storage, transport, and packaging. The lack of such

infrastructure reduces shelf life, increases wastage, and makes Indian organic produce less competitive in global markets.

Limited Domestic Market Development: While exports are growing, the domestic organic market is still underdeveloped in many regions. Weak retail networks, limited organic outlets, and inadequate promotion constrain market growth.

Strategies for Improvement: To overcome the challenges associated with certification and marketing, a combination of policy support, technological innovations, and farmer-consumer linkages is essential. The following strategies can significantly improve the adoption and success of organic horticultural produce:

Promotion of PGS-India (Participatory Guarantee System): PGS-India provides a low-cost, community-based certification system that is especially beneficial for small and marginal farmers. Since it does not involve high inspection costs, it promotes inclusiveness and enables farmer groups to access local and regional markets.

Strengthening FPOs and Cooperatives: By forming Farmer Producer Organizations (FPOs) and cooperatives, farmers can collectively manage certification, reduce costs, and negotiate better prices in the market. Such organizations also help in bulk marketing, consistent supply, and quality control.

Government Support and Policy Interventions: The government can play a crucial role by subsidizing certification fees, supporting cluster-based organic farming schemes like Paramparagat Krishi Vikas Yojana (PKVY), and promoting the "Jaivik Bharat" brand to establish a national identity for organic produce.

Digital Marketing and E-Commerce: The use of online platforms, mobile apps, and digital traceability systems (such as blockchain and QR codes) enhances consumer confidence. Traceability apps allow buyers to track produce from farm to fork, ensuring authenticity and building trust in certified organic products.

Awareness and Consumer Education Campaigns: Educating consumers about the health, nutritional, and environmental benefits of organic horticultural produce is crucial. Awareness programs, organic food fairs, and campaigns highlighting certification logos (India Organic, Jaivik Bharat, USDA Organic) can create stronger demand and reduce market exploitation.

Improved Infrastructure and Cold Chain Development: Investment in cold storage, refrigerated transport, and eco-friendly packaging will reduce post-harvest losses and improve competitiveness of perishable horticultural produce in both domestic and international markets.

Conclusion

Certification and marketing form the dual pillars that determine the success of organic horticultural produce in today's competitive food system. Certification guarantees authenticity, transparency and adherence to organic standards, thereby safeguarding consumers against false claims and enabling access to high-value domestic and internati-

onal markets. Marketing, on the other hand, ensures profitability, consumer reach, and long-term sustainability by connecting producers to diverse channels ranging from farmers' markets to global export destinations.Despite promising opportunities, challenges such as high certification costs, complex documentation, weak supply chains, and limited consumer awareness hinder the growth of organic horticulture. Addressing these barriers requires a multi-pronged approach that includes low-cost certification models like PGS-India, strengthened farmer cooperatives and FPOs, robust government support, digital innovations for traceability, and awareness campaigns to build consumer trust.

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Consumers and MSME Products: An Analysis from Sringeri Taluk

Marka Maheshnath, Shivakumara C. and Bharath Kumar T. P.

Introduction

Micro, Small and Medium Enterprises (MSMEs) are the backbone of India's local economy. They produce food items, spices, soaps, pickles, and other everyday products that reach millions of households. To understand how rural consumers use these products, a study was carried out in Sringeri Taluk, Chikkamagaluru district, covering 26 respondents. The study collected information on consumer usage patterns, preferences, satisfaction, and decision-making processes regarding MSME products. This article presents the findings in an easy-to-read manner, highlighting the voices of local consumers and what their choices mean for small businesses.

Profile of the Respondents

The socio-economic background of the respondents reflects the diversity of rural society.

Gender: 73% of respondents were men, while 27% were women. This shows that men often dominate household purchasing decisions, but women are slowly becoming more active consumers.

Age: A majority were young, with 42% below 25 years and another 54% between 25-50 years. Only one respondent was above 50. Youthfulness indicates openness to trying new products.

Caste background: 38% belonged to Scheduled Castes, 23% to Scheduled Tribes, and 35% to OBCs.

Family size: Almost all families (92%) were medium-sized (4-8 members).

Education: 39% had studied up to high school, 31% up to pre-university, while only 19% were graduates and 12% postgraduates. Thus, most consumers had basic to moderate education, sufficient to make informed choices.

Annual income: The average family income was ₹1,28,346, with most households earning between ₹50,000 and ₹1,50,000 a year. This profile indicates that the typical consumer of MSME products in Sringeri is a young, moderately educated man from a middle-income rural household.

Gender and Consumer Behavior

Out of 26 consumers, 18 were men (69%) and 8 were women (31%). Traditionally, men take the lead in purchasing decisions in rural areas, especially when it comes to market-based products. However, women too are beginning to influence choices, particularly in food-related purchases. For MSMEs, this suggests that marketing strategies should target

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both men and women, with special efforts to attract women as key decision-makers.

Age and Consumer Categories

The study found that consumers between 25-40 years form the largest group. These are household managers responsible for day-to-day purchases. Younger consumers (under 25) are also active, showing that MSME products appeal to multiple age groups. This diversity is an advantage MSME products are not age-restricted but have multi-generational appeal.

Education and Awareness: Education shapes how consumers view products. The study showed that most respondents had high school or pre-university education. This means that even with basic literacy, consumers are aware of product features such as taste, quality, and price. Importantly, even graduates and postgraduates are purchasing MSME products, which highlights that these goods are not limited to low-literacy groups but widely accepted.

Occupation and Buying Power: Consumers were mainly farmers, private employees, or self-employed individuals. Farmers buying MSME food products reflect local trust and support for homegrown enterprises. Salaried employees, with steady monthly income, form a reliable customer base for repeat purchases. Thus, MSMEs are well-positioned to serve both agrarian households and working-class consumers.

Income and Affordability: Nearly half the consumers (46%) fall in the ₹50,000-₹1,50,000 annual income range. This is the rural middle class. For them, price matters as much as quality. If products are affordable and trustworthy, they are ready to choose MSME goods over big brands. This finding reinforces the need for MSMEs to maintain a balance between price and quality.

Popular MSME Products: Consumers in Sringeri purchase a wide variety of local MSME products, especially daily-use food items.

- ✓ Banana chips (81%) and spice powders (85%) were the most popular.
- ✓ Sambar powder (73%), homemade pickles (50%), and medicinal soaps (50%) also had strong demand.
- ✓ Less frequently purchased items included potato chips (15%) and chocolates (12%).

Clearly, MSME products are strongly associated with traditional foods and local flavors. Consumers trust these over mass-produced alternatives.

Frequency of Purchases: The products are not occasional buys but part of routine consumption.

- ✓ 85% purchase them weekly once,
- ✓ 12% purchase monthly once, and
- ✓ Only 1 person reported buying 2-3 times a week.

This regularity means MSME products enjoy stable and recurring demand.

Place of Purchase: All respondents (100%) buy MSME products from local markets. None reported online shopping or buying directly from producers. This reflects both strong local distribution networks and the limited penetration of e-commerce in rural areas. For MSMEs, it signals the need to expand into

digital platforms while strengthening ties with traditional retailers.

Key Factors in Choosing Products: When asked why they preferred certain products, consumers gave these priorities:

- ✓ Quality (88%)
- ✓ Taste (85%)
- ✓ Price (4%)
- ✓ Local homemade nature (19%)
- ✓ Packaging (0%)

It is striking that quality and taste dominate decisions, while packaging plays no role at all. This is the reverse of urban markets where branding and packaging strongly influence buyers. For rural MSMEs, the focus must remain on authenticity and freshness.

Preference for Local over Branded Products: A strong 88% of consumers preferred MSME products over branded alternatives. The reasons include:

- ✓ Better taste
- ✓ Natural ingredients
- ✓ Lower cost
- ✓ Nutritional value
- ✓ Support for local producers

This finding shows that local MSMEs are competitive with big brands when it comes to consumer trust.

Recommendation Behavior: Perhaps the strongest indicator of satisfaction-100% of consumers said they would recommend MSME products to others. This "word-of-mouth" marketing is a priceless advantage for small businesses, as it builds trust more effectively than paid advertisements.

Problems Faced by Consumers: Despite positive feedback, consumers reported some challenges:

- ✓ High prices (42%)
- ✓ Low availability (35%)
- ✓ Short shelf life (19%)
- ✓ Lack of certification (4%)

Packaging was not considered a major issue. These insights show that MSMEs need to improve supply consistency, reduce costs where possible, and build credibility through certifications.

Satisfaction Levels: Overall, consumers expressed high satisfaction with MSME products. Minor complaints related to quality consistency and packaging. But in general, people felt local products met their needs better than branded ones.

One 35-year-old father put it beautifully:

"Our village banana chips are second to none. The taste is better than any brand, and the price is fair."

Key Findings

- ✓ MSME products are widely accepted in Sringeri's rural markets.
- ✓ Consumers are mostly young, moderately educated, and middle-income.
- ✓ Quality and taste outweigh packaging and branding in decision-making.
- ✓ Local trust is strong consumers prefer rural MSME products over branded goods.
- ✓ Main challenges include pricing, availability, and certification.

Conclusions

The study highlights that MSMEs enjoy natural goodwill among rural consumers. However, challenges like limited reach, price sensitivity, and certification need attention. Consumers are loyal, but their trust must be strengthened through consistent quality and fair pricing.

Recommendations

Balance Price and Quality: Keep products affordable without compromising standards.

Target Low-Income Groups: Special marketing strategies should reach price-sensitive customers.

Strengthen Local Retailers: Provide training and promotional support to village-level sellers.

Explore Online Channels: Gradually build e-commerce presence for wider markets.

Enhance Certification and Branding: Authentic seals, labels, and better packaging can improve trust.

Participation of Tribal Women in Agriculture and Role

Suchismita Sahoo and Shardinjay Singh

Introduction

Agriculture has always been the backbone of rural and tribal communities in India. In tribal areas, farming is not only an occupation but also a way of life, deeply interlinked with culture, traditions, and survival. Within this framework, tribal women play a vital role. Their contribution goes beyond mere participation in farming activities; they are the custodians of indigenous knowledge, biodiversity conservation, and food security of their families. However, their work often remains invisible and undervalued. This article highlights the extent of participation of tribal women in agriculture, the types of activities they perform, challenges they face, and the strategies required to empower them.

Role of Tribal Women in Agriculture

Crop Production: Tribal women actively engage in sowing, transplanting, weeding, and harvesting. In shifting cultivation areas, they are equally involved in clearing land, preparing seedbeds, and preserving traditional seeds. Their skills in seed selection and storage ensure the continuity of local crop varieties.

Horticulture and Kitchen Gardens: Many tribal families cultivate fruits, vegetables, and tubers around their homesteads. Women take primary responsibility for nurturing these gardens, which not only supplement family nutrition but also act as a small source of income.

Animal Husbandry: Along with crop cultivation, tribal women rear livestock such as goats, poultry, pigs, and cattle. They are responsible for feeding, milking, cleaning sheds, and utilizing dung for manure. These activities contribute significantly to household earnings and nutrition.

Collection of Forest Produce: Tribal women also depend on forests for food, fodder, fuelwood, and medicinal plants. Non-timber forest products (NTFPs) like mahua flowers, tendu leaves, and lac are collected and processed mainly by women, supplementing agricultural income.

Post-harvest and Processing Work: Women handle threshing, winnowing, drying, storing, and processing of crops. They ensure safe storage of grains and seeds, thereby contributing to household food security throughout the year

Indigenous Knowledge and Skills

Tribal women possess rich indigenous knowledge regarding soil fertility management, mixed cropping, pest control using herbal extracts, and preservation of traditional seeds. Their practices are environment-friendly and sustainable. For instance, in shifting cultivation systems, women play a central role in deciding crop combinations that maintain soil fertility and reduce risk of crop failure.

Challenges Faced by Tribal Women in Agriculture

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Despite their immense contribution, tribal women face multiple constraints:

Lack of Land Ownership: In most cases, land is registered in the name of men, leaving women with little control over resources.

Limited Access to Credit and Technology: Tribal women rarely access institutional loans or modern agricultural equipment, which restricts productivity.

Workload and Drudgery: Along with farming, they shoulder household responsibilities, resulting in long working hours and physical strain.

Illiteracy and Lack of Awareness: Low educational levels reduce their ability to participate in training programs or government schemes.

Market Exclusion: Women often lack direct access to markets, forcing them to depend on middlemen who exploit them with low prices.

Health Issues: Malnutrition, anemia, and lack of healthcare facilities weaken their productivity and overall well-being.

Importance of Empowering Tribal Women in Agriculture

Empowering tribal women is not only a matter of gender justice but also a necessity for sustainable agricultural development. Women's involvement ensures better household food security, higher productivity, and preservation of biodiversity. When tribal women are empowered with training, credit facilities, and decision-making power, they can transform agricultural practices and uplift their communities.

Strategies for Improvement

Land and Resource Rights: Ensuring joint land ownership for women can increase their security and bargaining power.

Skill Development and Training: Capacity-building programs should focus on modern farming techniques while respecting indigenous knowledge.

Access to Credit and Inputs: Providing easy loans, seeds, fertilizers, and tools directly to women can enhance productivity.

Formation of Self-Help Groups (SHGs): SHGs can strengthen collective bargaining, enable savings, and improve access to markets.

Promotion of Value Addition: Training in processing and packaging agricultural produce can fetch better market prices.

Improved Healthcare and Nutrition: Special programs targeting health and nutrition will increase women's efficiency and reduce workload stress.

Recognition of Women's Contribution: Awareness campaigns are needed to highlight women's role and secure their place in agricultural decision-making.

Conclusion

Tribal women are the backbone of tribal agriculture. Their hard work, knowledge, and commitment sustain not only their families but also the cultural and ecological balance of their communities. Yet, their contributions remain undervalued and underrecognized. To ensure inclusive and sustainable rural development, policies must prioritize the empowerment of tribal women in agriculture. Providing them with land rights, access

to credit, technology, and decision-making platforms will not only improve agricultural productivity but also strengthen the socio-economic fabric of tribal society.

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Uses of Lac in Daily Life

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Introduction

Lac, often called the "golden resin of India," is a natural secretion produced by the lac insect (*Kerria lacca*). For centuries, lac has played a significant role in Indian culture, economy, and daily life. Beyond its economic importance, lac is a versatile material used in industries, handicrafts, pharmaceuticals, food, and traditional rituals. Its biodegradability, non-toxicity, and natural origin make it a sustainable alternative to synthetic resins. Lac is available in various forms, including sticklac, seedlac, shellac, lac dye, and lac wax, each with unique applications. Understanding its diverse uses provides insight into why lac cultivation remains a crucial livelihood option for rural and tribal communities.

Lac in Household and Domestic Use

Decorative Items and Handicrafts

- ✓ Tribal and rural artisans use lac to create bangles, beads, ornaments, toys, and decorative items.
- ✓ These items are not only aesthetically appealing but also culturally significant in festivals, marriages, and rituals.
- ✓ Lac bangles, in particular, are traditional adornments for women in many Indian communities.

Polishes and Coatings

- ✓ Lac is used to polish wooden furniture, utensils, and decorative objects.
- ✓ Shellac, a refined form of lac, provides a smooth, glossy and protective finish.
- ✓ Being natural and non-toxic, it is preferred over synthetic varnishes for items that come in contact with food.

Traditional Applications

- ✓ Lac is used in folk medicine, as coatings for herbal medicines or small containers.
- ✓ In certain rituals, lac ornaments and decorations hold religious and cultural significance, symbolizing prosperity and auspiciousness.

Lac in Food and Confectionery

Food Coating

- ✓ Lac, in the form of bleached shellac, is widely used as a glazing agent for fruits, candies, and chocolates.
- ✓ It prevents moisture loss, adds a glossy finish, and extends shelf life.

Edible Uses in Traditional Food

- ✓ Lac has been used to coat traditional sweets and medicinal tablets to protect them from humidity and oxidation.
- ✓ As a natural product, it is preferred for organic and health-conscious food markets.

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Preservation

- ✓ Lac coating prevents microbial growth and oxidation in certain foods, acting as a natural preservative.

Lac in Pharmaceuticals

Capsule Coatings

- ✓ Shellac and bleached lac are used to coat medicinal capsules and tablets, providing protection against moisture and enhancing shelf life.
- ✓ It is non-toxic, biodegradable, and easily digestible, making it ideal for pharmaceuticals.

Ointments and Creams

- ✓ Lac wax, derived from the processing of sticklac, is used as a base in ointments, creams, and lipsticks.
- ✓ It helps in emulsification, consistency, and smooth application.

Traditional Medicine

- ✓ In Ayurvedic preparations, lac is sometimes used as a binder or coating agent, helping preserve herbal compounds.

Lac in Industrial Applications

Varnishes and Wood Finishes

- ✓ Shellac is widely used in furniture polishing, wooden crafts, and musical instruments.
- ✓ It forms a hard, glossy, and water-resistant layer that enhances aesthetics and durability.

Paints and Adhesives

- ✓ Lac serves as a natural binder in paints and adhesives, reducing dependence on synthetic chemicals.
- ✓ Its eco-friendly nature makes it suitable for environmentally conscious industries.

Electrical Insulation

- ✓ Shellac is an excellent insulator for wires and electrical components.
- ✓ Its non-conductivity and heat resistance make it valuable in electrical and electronic applications.

Printing Inks and Dyes

- ✓ Lac dye, obtained during processing, is used in textiles, leather, and printing industries.
- ✓ It provides natural red and brown shades, favored for traditional fabrics and handicrafts.

Lac in Cosmetics and Personal Care

Lipsticks and Lip Gloss

- ✓ Lac wax imparts gloss, texture, and hardness to lipsticks and lip glosses.
- ✓ It is safe for consumption and enhances product longevity.

Nail Polish and Hair Care Products

- ✓ Lac derivatives are used in nail enamels and hair-styling products for shine and durability.
- ✓ Being natural, they offer a non-toxic alternative to synthetic resins.

Body Art and Decorative Uses

- ✓ In certain regions, lac is used for temporary body decoration and jewelry, especially during cultural festivals.

Lac in Traditional and Cultural Uses

Religious and Ritual Significance

- ✓ Lac bangles, decorative beads, and ornaments are considered auspicious in Hindu rituals and ceremonies.

- ✓ Used in weddings, festivals, and religious offerings.

Cultural Heritage

- ✓ Lac crafts represent tribal art and traditional craftsmanship.
- ✓ Promotes women's empowerment as they are often the primary artisans involved in lac processing and handicraft production.

Tourism and Handicraft Industry

- ✓ Lac handicrafts contribute to rural tourism and local economies, attracting visitors to tribal and rural craft centers.

Advantages of Lac in Daily Life

Eco-Friendly: Being a natural resin, lac is biodegradable and sustainable.

Non-Toxic: Safe for food, pharmaceuticals, and cosmetics.

Versatile: Applicable in multiple industries and traditional practices.

Cultural Value: Preserves tribal heritage and promotes local economies.

Renewable: Lac insects and host trees ensure continuous production if managed sustainably.

Challenges in Using Lac

Quality Variation: Resin quality varies with insect strain, host tree, and processing method.

Market Awareness: Consumers often prefer synthetic alternatives due to lower cost.

Processing Expertise: High-quality shellac and lac products require skillful processing.

Sustainability Threats: Overharvesting of host trees or improper management can affect resin availability.

These challenges can be mitigated through scientific cultivation, community awareness, and value addition.

Conclusion

Lac is a multi-purpose natural resin with extensive applications in daily life, industry, and culture. From bangles and handicrafts to food coatings, medicines, varnishes, and cosmetics, lac exemplifies a product that bridges tradition and modernity. Its eco-friendly and renewable nature ensures that it remains relevant in sustainable development and rural livelihoods. By promoting lac cultivation and encouraging its diversified uses, India can strengthen rural economies, preserve tribal heritage, and provide environmentally responsible alternatives in multiple industries. Lac is not just a resin it is a symbol of culture, sustainability, and livelihood security, demonstrating how a tiny insect can generate substantial socio-economic impact. Lac proves that natural products, when utilized wisely, can enrich daily life, support economies, and protect the environment simultaneously.

Lac Cultivation: A Source of Sustainable Rural Livelihood

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Introduction

Sustainability in rural economies has become a pressing concern in the 21st century. Rapid urbanization, deforestation, shrinking farm sizes, and changing climate patterns are threatening the survival of traditional agricultural systems. In such circumstances, the search for sustainable, eco-friendly, and income-generating alternatives for rural and tribal communities has highlighted the importance of lac cultivation. Lac is a natural resin secreted by the tiny insect *Kerria lacca*, which thrives on certain host trees like *Kusum* (*Schleichera oleosa*), *Palas* (*Butea monosperma*), *Ber* (*Ziziphus mauritiana*), and *Khair* (*Acacia catechu*). For centuries, lac has been cultivated in India by tribal farmers as a source of livelihood. This forest-based enterprise not only generates cash income but also promotes biodiversity, forest conservation, and women's empowerment. India is the world leader in lac production, contributing nearly 80-85% of global supply. States like Jharkhand, Chhattisgarh, West Bengal, Odisha, and Madhya Pradesh are the primary hubs of cultivation. For rural and tribal households in these regions, lac cultivation acts as a lifeline supplementing subsistence farming and providing sustainable income even during agricultural lean seasons.

The Process of Lac Cultivation

Lac cultivation follows a systematic biological cycle of the lac insect. The key stages are:

Inoculation of Broodlac: Twigs encrusted with live lac insects (called broodlac) are tied to fresh twigs of host trees. The young insects (crawlers) emerge and settle on tender shoots to feed on sap.

Resin Secretion: While feeding, insects secrete a resinous substance that covers their bodies and forms a protective shell. Over time, this resin accumulates on branches, appearing as encrustations.

Colony Development: The insects continue to multiply, and the resin becomes thicker, forming what is known as sticklac.

Harvesting: After about 4-6 months, the encrusted branches are scraped off and collected as sticklac.

Processing: Sticklac is crushed, sieved, and washed to remove impurities, yielding seedlac. Further refining produces shellac, button lac, and bleached lac. By-products like lac dye and lac wax also have significant commercial value.

This cycle is repeated twice a year, providing farmers with multiple harvests and year-round opportunities for income.

Products and Uses of Lac

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Lac is a versatile material with wide applications:

Shellac: Used in varnishes, polishes, paints, electrical insulation, and as a natural adhesive.

Food Industry: Used as a coating for confectionery, fruits, and medicines due to its non-toxic nature.

Pharmaceuticals: Bleached lac and lac wax are used in capsule coatings and drug delivery systems.

Handicrafts: Tribal women craft beautiful lac bangles, toys, and ornaments, which are culturally significant in India.

By-products: Lac dye for textiles and cosmetics, lac wax for polishes, candles, and confectionery.

Because lac is biodegradable, eco-friendly, and non-toxic, its demand is rising as an alternative to synthetic resins.

Lac and Rural Livelihoods

Lac cultivation provides multiple benefits to rural and tribal households:

Cash Income for Tribals: For many families in Jharkhand, Chhattisgarh, and Odisha, lac is the primary source of cash earnings. Unlike subsistence crops, which are grown mainly for home consumption, lac is cultivated primarily for sale in local and export markets.

Employment Generation: Lac cultivation is labor-intensive, requiring activities such as host tree care, inoculation, harvesting, processing, and marketing. This creates employment opportunities for both men and women.

Women Empowerment: Women are heavily involved in processing lac into bangles, ornaments, and decorative products, which not only generates income but also preserves cultural traditions.

Low Investment, High Returns: Lac farming requires minimal investment only the availability of host trees and broodlac. With government support, even landless or marginal farmers can adopt this enterprise.

Supplementary to Agriculture: Lac does not compete with food crops for land. It is grown on host trees, many of which grow naturally in forests or on field bunds. Thus, it supplements agricultural income without disturbing food security.

Environmental Sustainability of Lac Cultivation

Lac cultivation is not just profitable but also eco-friendly.

Conservation of Trees: Farmers preserve and protect host trees, preventing deforestation.

Prevention of Forest Fires: Tribal communities guard lac-bearing trees from fire and grazing to protect their source of income.

Biodiversity Promotion: Lac insects contribute to ecosystem health by forming habitats for other organisms.

Green Alternative: Lac replaces harmful synthetic chemicals in industries with a biodegradable natural resin.

Thus, lac cultivation perfectly aligns with the goals of sustainable development by balancing economic, social, and environmental needs.

Challenges in Lac Cultivation

Despite its benefits, lac cultivation faces several obstacles:

Insect Pests and Predators: Enemies like

Eublemma amabilis (white moth) destroy large portions of lac crops.

Climatic Stress: Droughts, extreme heat, or untimely rains reduce survival of lac insects.

Deforestation: Decline in host tree populations threatens expansion.

Market Issues: Farmers often depend on middlemen and receive low prices.

Traditional Practices: Lack of modern scientific methods reduces yield and quality.

Strategies for Promoting Lac Cultivation

For lac cultivation to become a robust source of sustainable livelihood, the following measures are important:

Scientific Training: Educating farmers about scientific inoculation, pest control, and processing.

Expansion of Host Trees: Plantation of Kusum, Palas, and Ber trees under agroforestry and afforestation programs.

Value Addition at Village Level: Promoting small processing units for shellac, bleached lac, and handicrafts.

Strengthening Cooperatives: Forming self-help groups (SHGs) and cooperatives to reduce dependence on middlemen.

Government and Institutional Support: Initiatives by the National Lac and Resin Development Corporation (NLRDC), state forest departments, and NGOs must be expanded.

Research and Innovation: Development of pest-resistant strains, improved broodlac, and advanced processing technologies.

Conclusion

Lac cultivation stands as a model of sustainable rural livelihood, combining economic viability with environmental responsibility. It provides cash income to tribal families, empowers women, conserves forests, and supports biodiversity. Being a renewable, eco-friendly product with increasing global demand, lac offers immense potential to uplift rural economies. If promoted with scientific training, cooperative marketing, and government support, lac cultivation can become a powerful driver of poverty alleviation, livelihood security, and sustainable development in rural India. For the tribal farmer, lac is more than resin it is hope, heritage, and a bridge between tradition and modernity. Indeed, lac cultivation proves that sometimes, the smallest insect can create the largest impact on rural sustainability.

Cultivation of Custard Apple for Nutrient Security

Sunita Yadav, Suresh Kumar Jat and Yougendra Singh

Custard apple (*Annona squamosa* L.) can be called as a delicacy of dry region due to its very sweet delicate flesh. It is a deciduous or semi deciduous tall woody shrub of about 5-6 meters height having irregularly spreading branches. The fruits are rich in carbohydrate mainly in the form of sugar (23.5%), protein (1.6%), calcium (17 mg/100 g), phosphorus (47 mg/100 g) and iron (1.5 mg/100 g). The custard apple of India the sitaphal or sugar apple of sweet sop has many relatives. It is one of the finest fruits introduced in India from tropical America and found in wild form in many parts of the country. Fruits are dark greening brown in colour and marked with depressions giving it a quilted appearance; its pulp is reddish yellow, sweetish, and very soft (hence the common name); the kernels of the seeds are said to be poisonous. Custard apple is known for its edible fruits, and the tree grows as a small sapling, rising from 3 m and reaching up to 8 m, with large, randomly spread branches having brownish or light brownish bark with thin leaves. Custard apple has been utilized as a natural medicine and in various other food applications, e.g., its pulp is utilized as a flavouring agent in ice cream, and 50-80% of custard apple fruit is edible and can be pulped as juice.

Cultivating custard apple can contribute to nutrient security by providing a source of vitamins and minerals while promoting sustainable farming practices. Sustainable farming practices, like organic methods, can further enhance the nutrient density of the fruit and improve soil health. Custard apples are a good source of vitamin C, which is essential for immunity, and B-complex vitamins, which play various roles in the body. They also contain minerals like magnesium and potassium, which are important for bone health, nerve function and muscle contract-ion. Custard apples are packed with antioxidants, including carotenoids, flavonoids, and vitamin C, which can help protect the body against damage from free radicals.

Climatic and soil requirements: A warm climate (not very hot) with high humidity and milld winter will be the ideal climatic condition for the best growth and yield of most of the *Annona sp.* Except *A. cherimola.* Though they can tolerate extremes of temperature (beoow freezing and upto 40^{o}C), such extermes won't be ideal for production of flowers and fruits. They can be grown from sea level up to 1000 meteres. Where the summer temperature is very high (more than 40^{o}C) and humidity is low there will

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be no fruitest though the flowering is profuse. An annual rainfall of 500-750 mm is adequate of growth and fruiting. Annonas can be grown in varied soil right from heavy clay upto sandy one. They can also be grown on rocky, marginal and even waste lands. However for best yield, a well drained fertile soil with neutral pH will be ideal. The plants are shallow rooted and hence a deep soil is not necessary. They can be grown on slightly alkaline soil and with irrigation water having slight higher pH and salinity.

Cultivars

Balanagar: It is a cultivar of *A. squamosa*. The fruits are greenish yellow in colour. Each fruit weight 130-140 g. TSS is 20.7^{o} brix.

Red sitaphal: It probably originated as chance seedling. Fruits of this cultivar through belong to *A. squamosa* are pinkish dark with erythrite red pulp. Average fruit weight is 150-160 g with 22.3^{o} brix TSS.

Mammoth: It is a cultivar of *A. squamosa*. The weight of the fruit is about 125 g, TSS is 20^{o} brix.

Arka Sahan: It is an inter-specific hybrid developed at IIHR, Bangalore. Fruits are big (210 g) skin is light green in colour with waxy bloom, moderately thick with large flat eyes. Fruits have improved shelf life viz., take 7 days to ripe, 4 days more than 'Mammoth'. The creamy white flesh in juicy with mild pleasant aroma and tender with sparse seeds (9/100 g of fruit weight). The fruit of this variety is also characterized by large segments or flakes and many of which are seedless. Flesh is very sweet (30^{o}brix) compared to 24^{o}brix in Mammoth. Average yield is 12 tonnes/ha.

APK (Ca)-1: It is a clonal selection from a high yielding type in State Horticultural Farm, Courtallam of Tirunelveli District of Tamilnadu developed at Regional Research Station, Aruppukkottai. It is a high yielder in rainfed vertisol (Black soil) 14.90 kg tree^{-1}, 30.7% more than Balanagar. Each fruit weighs 207g. Average number of fruits would be 72 tree^{-1}. SS 24.5^{o} Brix, acidity 0.2%. Adapted to semiarid plains.

Propagation and planting: Annona is propagated commonly by seeds. Fresh seeds germinate in 20-30 days. Seed propagation results in variability in plant vigour, prolonged juvenile and inferior fruit quality. Vegetative propagation by budding or inarching on seedlings and *A. reticulata* ensures genetic uniformity. Budding is usually done in early spring or in the autumn. Inarching should be carried out in early spring using one-year old mature scion and more than one-year old root stock. A spacing of 5 M x 5 M is recommended for annonas. At planting, 50 g. Phosphobacterium +150 g of Vesicular Arbuscular Mycorrhiza are inoculated on the roots and the plants are planted in the pits filled with 10 kg of FYM and top soil. This helps in rapid growth of roots and better establishment of plants, especially in dry regions. Since annonas are mostly cultivated on poor soils, manuring is necessary for production of good crops. Application of 10 kg Farmyard manure, 250 g N, 125 g P_2O_5 and 250 g K_2O is recommended per tree. The fertilizers should be applied at the commencement of rainy season.

Inter-cultivation: For good plant growth, the weeding should be done to keep away the weeds. Inter-cropping with some legumes, peas, beans and marigold flowers are commonly taken by the growers. Normally, no crop is taken during winter as the plants go under rest. The problem of poor fruit set in custard apple can be overcome to a large extent by application of GA at a concentration of 50ppm. Dipping of freshly opened flowers in GA ensures better fruit-set, better fruit retention, increased fruit size and weight with less seed. The crop can be sprayed with NAA 20 ppm four times at weekly interval during flowering (March-April) to encourage fruit set. Irrigation and mulching during summer season also helps to prevent fruit drop.

Irrigation: In general, Custard apple is grown as a rainfed crop, and no irrigation given. However, for early and bumper harvest of the crop. Irrigation on flowering i.e. from May should be given till regular monsoon starts. For better flowering and fruit setting, mist sprinkling is better over flood or drip system of irrigation as it keeps to lower down the temperatures and to increase in the relative humidity.

Care of young orchard: The gap filling is to be done as early as possible. Stagnation of water during first monsoon should be taken care of, if the planting is done on imprevious soils or ill drained soils.

Pests

Mealy bug: *Ferrisia virgata* Cockerell (Hemiptera: Pseudococcidae)

Fruit fly: *Bactrocera spp, B. zonata* Saunders (Diptera: Tephritidae)

Scales: *Ceroplastes floridensis* Comstock (Hemiptera: Coccidae)

Fruit boring caterpillar: *Heterographis bengalella* Ragonot (Lepidoptera: Pyralidae)

Integrated Pest Management strategies

- ✓ Collect and destroy the mealy bug infested leaves, twigs and fruits.
- ✓ Flooding of orchard with water in the month of October kill the eggs.
- ✓ Plough of orchard in November. Avoid plant stresses - healthy plants are much less susceptible to attack
- ✓ Release *Cryptolaemous montrouzieri* beetles @ 10 tree^{-1} or @ 30 larvae plant^{-1} twice at 15 days interval.
- ✓ The Coccinellid *Menochilus* (Chilomenes) *sexmaculatus* (F) is a predator of the nymphs and adults, and the Hymenopterous parasite *Anaysis alcocki* (Ashm.) *Anagyrus dactylopii* and *Aenasius advena* are three parasitoids on mealy bugs.
- ✓ Release of coccinellid *Scymnus coccivora* @ 10 beetles tree^{-1} or @ 30 larvae plant^{-1} is a good predator of both nymphs and adults.
- ✓ Collect fallen infested fruits and destroy them.
- ✓ Provide summer ploughing to expose the pupae.
- ✓ Immersion of fruits in hot water (45 to 47°C) for 60 minutes to kill eggs and maggots Use 10 traps per acre of methyl eugenol.
- ✓ Field release of natural enemies *Opius compensates* and *Spalangia philippines.*
- ✓ Apply well rotten sheep manure @ 4 t acre^{-1} in

two splits or poultry manure in 2 splits Control ants and dust which can give the scale a competitive advantage.

- ✓ Field release of ladybird beetle.
- ✓ Adopt bagging of fruits.
- ✓ Use of braconid parasitoids (*Apanteles spp.*) to parasitize larvae.

Diseases

Fruit rot & Anthracnose: *Colletotrichum gloeosporioides* (Penz.) Penz. and Sacc. (Perfect stage *Glomerella cingulata* (Stoneman) Spauld. & *H. Schrenk*

Alternaria leaf spot: *Alternaria spp.*

Cylindrocladium leaf spot: *Cylindrocladium colhounii* and *Cylindrocladium scoparium*

Diplodia rot: *Botryodiplodia theobromae* Patouillard

Black canker: *Phomopsis annonacearum* (Bond) Mont.

Disease Management: Disease management in custard apple involves a combination of cultural practices, biological control, and chemical treatments. Cultural practices include removing and destroying infected plant parts, improving orchard hygiene, and using resistant varieties. Biological control utilizes natural enemies of pests and pathogens, while chemical treatments may involve applying fungicides or insecticides as needed.

- ✓ Proper sanitation of orchard by periodical removal of fallen plant debris and pruning of trees eradicates the fungus and checks further spread of the disease.
- ✓ Maintaining tree vigour with proper irrigation and fertilization.
- ✓ Fungicide sprays should begin when panicles first appear and continue at the recommended intervals until fruits are picked.
- ✓ Spraying the trees twice with Carbendazim (0.1%) or Mancozeb (0.2 %) or combination of Carbendazim 12 % + Mancozeb 63 % @ 0.1 % at 15 days interval during flowering to control blossom infection and twice during pea nut stage to prevent fruit infection.
- ✓ Alternate sprayings of Carbendazim and Mancozeb to avoid development of resistance in pathogen to fungicides.
- ✓ Spraying five times with *Pseudomonas fluorescens* FP 7 (0.5%) from flowering until harvest at 3 weeks interval reduces anthracnose incidence and improves fruit quality. For post harvest anthrcanose, fruits are dipped in hot water at 50 C for 30 min. in combination with 0.05 % carbendazim
- ✓ Three sprays of Streptocycline (200 ppm) or Agrimycin-100 (100 ppm) after first visual symptom at 10 days intervals. Monthly sprayings of Copper oxychloride (0.3%) checks the further spread. Removal of diseased fruits under storage. Dipping fruits in 200 ppm Agrimycin is effective.

Harvest and storage: The fruits are to be harvested at correct stage of maturity. Light green fruit colour, yellowish white colour between the carpels and initiation of cracking of the skin between the carpels

may be taken as maturity indices. The fruits are hand picked. The peak harvest period is October-November. A custard apple tree usually produces 80-100 fruits per tree after 4 to 5 years. The custard apples ripen with in a few days after harvest. The mature fruits can be stored at 15°C to 20°C with RH of 85-90% and low oxygen and ethylene but with 10% CO_2. Under such storage conditions, the fruts can be kept intact for 12-18 days. Additives like Saccharified starch (1:1), high voltage treatment and packing under nitrogen gas cover, sugar (1:2) were quite effective in extending the storage of pulp at 4°C (45 days) and -18°C (90 days) temperature.

Post-harvest handling: The fruits do not withstand cold storage as well as handling after ripening. Firm but mature fruits can be kept at 6°C temperature for about a week but such fruits loose aroma and attractiveness and also develop some cipid taste.

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Lac Cultivation: A Livelihood Resource for Tribal Peoples

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The major and most affordable source of both timber and non-timber items is always thought to be the forest. Nevertheless, forests only make up 1.7% of our nation's total GDP. In India, some 300.0 million tribal people and other local residents rely on forest resources either directly or indirectly. Minor forest products (MFP) provide all or part of the income for the tribal group, especially for women who live on the outskirts of forests. One of the main non-timber forest products that has historically given forest inhabitants jobs, income, and food security is lac. Small lac insects (*Laccifer lacca*) are raised for their valuable natural resin, color, and wax, which is secreted as lac. It is mostly made in South Asian nations including China, India, and Myanmar, China, Thailand and Indonesia. Lac is a natural commercial culture in forest host trees viz. *Butea monosperma* (palas), *Zizyphus mauritiana* (ber) and *Schleichera oleosa* (kusum) in India (Prasad *et al.*, 2004, 2006). Its cultivation plays a major role in environmental and ecological stability, socio-economic condition of the people and sub-forest people in India as well as in Asia (Singh and Chatterjee, 1994; Pal, 2009, 2010, 2011; Pal *et al.*, 2009; Pal and Bhattacharya, 2011; Singh *et al.*, 2011; Mohammad, 2004; Singh, *et al.*, 2011; Jaiswal *et al.*, 2011). India represents world's largest lac-producing country accounting for 80-90% of global production. The states where it is widely grown include Bihar, Jharkhand, Madhya Pradesh, West Bengal, Uttar Pradesh, Orissa, Maharashtra and Gujarat.

Lac cultivation or culture: There are two distinct strains of the lac insect in India, called Kusumi and Rangeeni The former is raised mainly on the Kusum trees and latter on all other lac hosts. Each of the strains produces two crops in a year, thus there are four crops which have been shown below:

Of the countries total production; 90% lac is obtained from the Rangeeni crops and only 10% from the Kusumi crops.

The two methods of lac cultivation are popular-

- ✓ Local cultivation
- ✓ Modern cultivation

Local cultivation: This is the crude and unscientific method of lac cultivation in which lac is collected from the trees growing in jungles. Lac is left for continuous self inoculation on the same tree and every time a partial crop is taken. The method of lac cultivation has generally failed to provide sustained supplies of brood lac for crop inoculations and

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optimum yield of lac.

Modern method: This method was developed by Indian Institute of Natural Resins and Gums, Ranchi and is known as coupe system. To get good crop, following points should kept:

Selection of suitable site: The site should be selected on the basis of host plants, where environmental conditions, suitable for host trees should be preferred. The excessive heat and cold should be avoided.

Pruining of host plants: This is an important and essential operation carried out with the object of inducing the tree to put forth maximum number of shoots suitable in condition, for successful colonisation by the larvae of the lac insect. Pruining should always be carried out lightly and branches, more than 2.5 cm in diameter should not be cut. The pruining is dependent upon the type of the host plant e.g. in case of ber trees, a large number of succulent shoots are produced after pruining while palas and kusumi do not ordinarily require pruining.

Inoculation of brood lac: Lac sticks bearing alive mother cells which produce lac larvae are known as brood lac. The brood lac sticks should be cut into convenient length of 15-30 cm and tied in succulent shoots of the host tree. The tying may be done either longitudinally or laterally. The brood lac (covered 15 to 20 times of its lenght) should be used for inoculation. The brood used for inoculation should not be left on the trees for more than 3 weeks because keeping beyond this time, there is a danger of enemies to spread. When the brood lac is removed from the trees it is known as phunki lac. There are following types of lac:

- ✓ **Ari-lac:** This is the immature lac and cutting of aril ac should be avoided.
- ✓ **Stick lac:** Mature lac harvested in the form of sticks is called as sticks lac.
- ✓ **Seed lac:** The lac obtained after removing and washing from the sticks is known as seed lac
- ✓ **Dust lac:** Dust lac is obtained after grinding the seed lac.
- ✓ **Shellac:** Shel lac is prepared after heating the seed lac and dust lac.

Scrapping of brood lac: When the brood lac sticks are removed from the trees, all other, either dead or rejected as unfit for brood purposes, is scraped as early as possible. The possible date of crop maturity may be known by the following points:

- ✓ Appearance of cracks in the lac before 15-20 days.
- ✓ Granular appearance of the body contents of the female lac insect.
- ✓ Eggs become separated from the masses
- ✓ The eggs seem to be granular
- ✓ The lac becomes dry and yellow in colour.

Washing of lac: The lac obtained after scrapping is washed with water and dried under shadow. The colour is obtained due to the washing which is used for various purposes.

Preparation of shell lac: The following are the methods for preparing the shell lac:

- ✓ Indian method
- ✓ Hydraulic method

- ✓ Solvent method
- ✓ Autoclave method

Indian method: It is the oldest method in which the seed lac is put in to long cloth bags of 6.5 cm width. The bag is tide with a pivot of wheel and circulated. The heat is also provided side by side. The melted lac due to the pressure comes out which is collected and made in the form of tablets.

Hydraulic method: This is a machine in which the seed lac is put in a cloth on which a spray of water is provided. The bottom of the machine in heated with steam by a pipi to get the lac melted. The lac is pressed by a plunger operated by hydraulic pressure and collected. To remove the moisture, the lac is heated in another machine and then stored after cooling.

Solvent method: The seed lac is dissolved in spirit and separated by distillation process. The spirit may be used for further washing.

Autoclave method: This process has been developed by Indian Institute of Natural Resins and Gums, Ranchi in which the seed lac is put in the bags of iron nets and heated in a special autoclave. The lac is collected on the lower surface of the autoclave. After sometime it is removed from here and heated again. The melted shel lac is spread into thin sheets and dried.

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Hybrid Seed Production in Safflower

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Abstract

Safflower (*Carthamus tinctorius* L.) is one of the oldest cultivated oilseed crops, known for its high-quality edible oil containing 24-36% oil content. The crop belongs to the family Asteraceae and is cultivated primarily during the *rabi* season in tropical and temperate regions. Hybrid seed production in safflower has gained significant importance for exploiting heterosis to overcome yield barriers and improve adaptation to adverse conditions. This discovery is supported by the development of various male sterility systems, including genetic male sterility (GMS), cytoplasmic male sterility (CMS), and cytoplasmic-genetic male sterility (CGMS). Commercial hybrids show a 25-35% yield advantage over conventional varieties under both irrigated and rainfed conditions. Safflower hybrids comprising different male sterility systems are being successfully cultivated across major safflower growing regions, including India, the USA and Australia.

Introduction

Safflower (*Carthamus tinctorius* L.) belongs to the family Asteraceae and is one of the most important oilseed crops cultivated worldwide. The genus Carthamus includes approximately 20 species, with *Carthamus tinctorius* being the only cultivated species. Safflower is grown in over 60 countries, with India ranking first in both area (41%) and production (29%) globally. In India, safflower is cultivated over 1.78 lakh hectares with a production of 1.44 lakh tons. The crop is primarily grown as a *rabi* season crop and is well-adapted to semi-arid regions with limited water availability. The development of hybrid varieties has emerged as a crucial strategy to enhance productivity and address the challenges of low seed yield, poor oil content, and susceptibility to diseases and pests.

Heterosis breeding in safflower offers significant potential for yield improvement, with hybrids showing 25-35% higher yields compared to conventional varieties.

Botanical Description

Safflower is an annual herbaceous plant with the following characteristics:

Plant Structure: Safflower plants are erect, much-branched, and typically reach heights of 60-150 cm, depending on the variety and growing conditions. The plant develops a strong taproot system that can penetrate up to 3.5 meters in depth, making it highly drought-tolerant.

Leaves: The leaves are alternate, sessile, and vary from entire to deeply lobed. They may be spiny or non-spiny, depending on the variety, with spiny types featuring sharp thorns along their leaf margins.

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Flowers: Safflower produces composite flower heads (capitula) containing 15-60 individual disc florets. The flowers are hermaphrodite, bright orange to red in colour, and are arranged in terminal capitula. Each floret develops into a single-seeded fruit called an achene.

Pollination: Safflower is predominantly self-pollinated but exhibits varying degrees of out-crossing (0-59%) depending on genotype and enviro-nmental conditions. The presence of pollinators, particularly honeybees, can significantly increase cross-pollination rates to nearly 100% in male-sterile lines.

Safflower Species	Common Name	Chromosome Number (2n=)	Oil Content (%)
Carthamus tinctorius	Safflower/ Kusum	24	24-36
Carthamus oxyacantha	Wild safflower	24	15-30%
Carthamus palaestinus	Palestine safflower	20	-

Land and Climatic Requirements

Soil Requirements: Safflower grows best on well-drained, fertile, medium to deep soils with good organic matter content. The crop prefers loamy to sandy-loam soils with neutral pH (6.5-7.5). It can tolerate slightly alkaline conditions but performs poorly in waterlogged or highly acidic soils. The crop is moderately tolerant to salinity.

Climatic Requirements: Safflower requires cool temperatures during early growth stages (15-20°C) for proper rosette development and higher tempera-tures (24-32°C) during flowering and seed development. The crop requires a 120-200 days growing period, depending on the variety. Minimum germination temperature is 2°C, while the optimum is around 15-16°C. The crop is frost-resistant up to -7°C during the seedling stage, but becomes sensitive to frost after the rosette stage.

Water Requirements: Safflower requires 300-320 mm of total water, with critical irrigation stages being:

- ✓ Rosette stage (30-35 days after sowing)
- ✓ Flower initiation stage (70-75 days after sowing)
- ✓ Seed development stage (100-105 days after sowing)

Hybrid Seed Production Systems

Male Sterility Systems

Genetic Male Sterility (GMS): Genetic male sterility in safflower is governed by recessive genes (ms ms). This system requires maintaining male-sterile lines by crossing with heterozygous male-fertile plants (Ms ms), producing 50% male-sterile and 50% male-fertile plants. The main limitation is the difficulty in identifying and removing male-fertile plants before flowering, making it labour-intensive for commercial seed production.

Cytoplasmic Male Sterility (CMS): CMS systems utilize sterile cytoplasm from wild Carthamus species. The first CMS system was reported from crosses between *Carthamus oxyacantha* and cultivated species. CMS lines show 100% pollen sterility and do not require roguing of male-fertile plants, making them ideal for commercial hybrid seed production.

Cytoplasmic-Genetic Male Sterility (CGMS): CGMS combines cytoplasmic sterility with nuclear

Popular Hybrid Varieties

Hybrid	Year Released	Male Sterility System	Yield (kg ha^{-1})	Oil Content (%)	Special Features
DSH-129	1997	GMS	2200	30	Wilt resistant
DSH-185	2013	CGMS	1430-1740	28-29	Fusarium wilt-resistant
NARI-NH-1	2002	GMS	1936	35	Non-spiny, all India
NARI-H-15	2006	GMS	2201	31	Spiny, aphid-tolerant
NARI-H-23	2014	TGMS	1711	35	Thermosensitive GMS

restorer genes. This system requires three lines:

- ✓ A-line (male-sterile line with sterile cytoplasm)
- ✓ B-line (maintainer line with fertile cytoplasm but same nuclear genes as A-line)
- ✓ R-line (restorer line with fertile cytoplasm and restorer genes)

Hybrid Seed Production Guidelines

Parent Line Maintenance

A-line Maintenance: Male-sterile lines must be maintained by crossing with their corresponding B-lines under isolation or controlled pollination. Pollen sterility should be confirmed by microscopic examination using acetocarmine staining.

B-line Maintenance: Maintainer lines are preserved through selfing under isolation bags or in isolated fields to prevent contamination from other varieties.

R-line Development: Restorer lines are selected based on their ability to restore fertility in test crosses with A-lines. Effective restorers should show 80-100% fertility restoration.

Field Layout and Isolation

Isolation Distance: Minimum isolation distances are, foundation seed is 700 m from other safflower varieties and certified seed is 400 m from other safflower varieties.

Row Ratio: A female-to-male ratio of 4:1 is recommended for optimal seed set and economic returns.

Staggered Sowing: Male parent (R-line) should be sown 5-7 days earlier than female parent (A-line) to ensure synchronous flowering.

Seed Rate and Sowing: A seed rate of 10-12 kg ha-^{1} from a certified agency is recommended. Sowing is done in last week of October to early in November.

Cultural Practices

Land Preparation: Prepare a fine, well-levelled seedbed with 2-3 ploughings followed by harrowing and levelling. Ensure proper drainage to prevent waterlogging.

Fertilizer Management: The recommended dose of fertilizers is as follows: apply 60-80 kg ha^{1} of nitrogen, 40 kg ha^{1} of phosphorus and 40 kg ha^{1} of potassium to the soil. Additionally, add 25 kg ha^{1} zinc sulphate in zinc-deficient soils. Apply full phosphorus and potash as a basal dose along with 1/3 nitrogen. Remaining nitrogen should be top-dressed at the first irrigation and vegetative growth.

Irrigation Management: Provide irrigation at critical stages:

- ✓ Pre-sowing irrigation for good germination
- ✓ Rosette stage (30-35 DAS)
- ✓ Flower initiation (70-75 DAS)
- ✓ Seed development (100-105 DAS)

Weed Management: Perform hand weeding when plants are 15-20 cm high. Pre-emergence herbicides can be used as per local recommendations.

Pollination Enhancement

Bee Colonies: Place 2-3 bee hives per hectare during flowering to enhance cross-pollination between A and R lines. Honeybees are the most effective pollinators for safflower.

Supplementary Pollination: Hand pollination may be practiced during unfavourable weather conditions to ensure adequate seed set.

Quality Control and Roguing

Pre-flowering Roguing: Remove off-type plants, diseased plants, and any volunteer plants before flowering based on morphological characteristics.

Flowering Stage Roguing: Remove any male-fertile plants from A-line rows and off-type plants from R-line rows.

Pre-harvest Roguing: Final roguing should be done to remove plants with different maturity or seed characteristics.

Plant Protection

Pest Management

Safflower caterpillar: Spray Quinalphos 25 EC @ 2 ml liter^{-1}

Aphids: Use Dimethoate 30 EC @ 1 ml liter^{-1} or introduce natural predators

Disease Management

Alternaria blight: Spray Mancozeb @ 2 g liter^{-1}

Fusarium wilt: Use resistant varieties and soil solarization

Root rot: Ensure proper drainage and avoid waterlogging

Harvesting and Post-Harvest Handling

Harvesting: Harvest when 75-80% of capitula turn brown and seeds become hard. In hybrid seed production, harvest male rows first to prevent contamination, then harvest female rows.

Maturity Indicators: On maturity, the capitula turn light brown, seeds become hard and acquire a characteristic colour and moisture content drops to 10-12%

Threshing: Dry the harvested crop for 2-3 days in the field before threshing. Use mechanical threshers or beat with sticks. Avoid over-drying, which may cause seed shattering.

Cleaning and Grading: Clean seeds using air-screen cleaners to remove chaff, broken seeds, and foreign matter. Grade seeds based on size and weight.

Storage: Dry seeds to 8% moisture content before storage. Store in moisture-proof containers with proper rodent control measures.

Seed Yield and Economics: With proper management, hybrid safflower seed production can yield up to 10-12 q ha^{-1} may be obtained.

Recent Advances

Thermosensitive Genetic Male Sterility (TGMS): Development of temperature-sensitive male sterile lines that show sterility at higher temperatures and fertility at lower temperatures, facilitating easier seed production.

Marker-Assisted Selection: Use of molecular markers for early identification of male sterility genes and restorer genes, reducing breeding time and improving selection efficiency.

Conclusion

Hybrid seed production in safflower represents a significant advancement in enhancing crop productivity and adaptation. The successful implementation of various male sterility systems, particularly CGMS, has made commercial hybrid seed production feasible. With proper attention to isolation, synchronization of flowering, quality control, and post-harvest handling, hybrid safflower cultivation can provide substantial yield advantages over conventional varieties. Continued research in molecular breeding, speed breeding, and development of enhanced male sterility systems will further improve the efficiency and cost-effectiveness of hybrid safflower seed production.

Integrated Nutrient Management for Sustainable Agriculture

Vinod Kumar Dhaked and Manisha Rathore

Abstract

Agriculture today faces the dual challenge of increasing crop productivity while maintaining soil health and minimizing environmental degradation. Integrated Nutrient Management (INM) is an approach that combines organic manures, chemical fertilizers, and biofertilizers in a balanced manner to supply nutrients efficiently. This article highlights the importance, components, benefits, challenges and future prospects of INM in achieving sustainable agriculture.

Introduction

Soil fertility is the foundation of sustainable agriculture. In the Green Revolution era, excessive reliance on chemical fertilizers improved yields but led to declining soil health, reduced organic matter, and nutrient imbalances. Integrated Nutrient Management (INM) has emerged as a holistic solution that ensures nutrient supply through a judicious mix of organic, inorganic and biological sources. It improves soil quality, enhances crop yield and maintains ecological balance.

Components of Integrated Nutrient Management

Organic Manures: Farmyard manure (FYM), compost, vermicompost and green manures adds organic carbon and improves soil structure. These enhance water-holding capacity and stimulate microbial activity.

Chemical Fertilizers: Provide readily available nutrients to meet the immediate demand of crops. Balanced use of NPK fertilizers prevents deficiency and ensures higher productivity.

Biofertilizers: Microorganisms like Rhizobium, Azotobacter, Azospirillum, Phosphate solubilizing bacteria (PSB) and Mycorrhiza plays a key role in fixing nitrogen, solubilizing phosphorus and mobilizing micronutrients.

Crop Residue Recycling: Incorporating straw, husk and other residues into soil returns nutrients and reduces waste.

Green Manuring: Crops like Sesbania and Dhaincha etc. fix atmospheric nitrogen and enrich the soil when incorporated.

Benefits of INM

Improved Soil Health: Enhances soil structure, organic matter, and microbial diversity.

Nutrient-Use Efficiency: Reduces nutrient losses due to leaching and volatilization.

Sustainability: Maintains long-term soil fertility and productivity.

Higher Yields: Provides balanced nutrition for

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optimum crop growth.

Environmental Protection: Reduces dependency on chemical fertilizers and minimizes pollution.

Challenges in Adoption

- ✓ Limited availability of quality biofertilizers and organic manures.
- ✓ Lack of farmer awareness about INM techniques.
- ✓ Region-specific variations in soil fertility demand customized approaches.
- ✓ Poor extension support in some rural areas.

Future Prospects

Government schemes promoting organic and natural farming can strengthen INM adoption. Use of ICT tools, soil health cards, and precision agriculture can guide farmers in nutrient management. Research on microbial consortia and nanofertilizers will further improve nutrient efficiency.

Conclusion

Integrated Nutrient Management is not just a technique but a sustainable farming philosophy. By balancing organic, inorganic, and biological nutrient sources, INM ensures soil health, higher productivity and environmental sustainability. Its large-scale adoption will be a key factor in achieving the goals of food security and sustainable agriculture in India.

Water-Saving Innovations and Smart Irrigation in 2025: Transforming Agriculture for a Sustainable Future

Shruti Kumari

Introduction

Water is the key to life and agriculture. Nevertheless, in 2025, the world remains plagued by a severe water crisis. Agriculture uses almost 70% of the world's freshwater, and issues like climate change, population growth, and urbanization are putting greater strain on this limited resource. Food demand will rise by almost 50% by 2050, whereas water availability will drop dramatically in most parts of the world. The task is straightforward: grow more food using less water. Water-conserving innovations and intelligent irrigation systems are taking center stage, leveraging precision irrigation, AI, IoT, renewable power, and improved water management practices. This article discusses recent developments, case studies, and challenges in implementing these innovations, with an eye on their ability to build climate-resilient and sustainable agriculture.

Water Challenges in Agriculture

Climate Change: Unpredictable rainfall, extended droughts, and intensified floods interfere with irrigation cycles.

Groundwater Depletion: Excessive extraction in nations such as India, China, and the USA jeopardizes water security.

Inefficient Irrigation: Conventional flood irrigation loses 40-60% of water.

Rising Competition: Cities, industries, and eco-systems increasingly compete with agriculture.

Without urgent innovation, water scarcity could reduce crop yields by up to 30% by 2050, risking global food security.

Smart Irrigation: Concept and Features

Smart irrigation is the use of digital techno-logy, automation and data-based insights to maximize water efficiency. It differs from convent-ional systems as it varies irrigation in real time according to soil, crop, and weather information.

Key Features

Soil Sensors: Measure moisture, temperature, and crop stress.

Automation: Systems regulate irrigation schedules without manual control.

Precision Delivery: Drip and micro-irrigation reduce losses.

Mobile Apps/Platforms: Provide real-time advisories to farmers.

Water-Saving Innovations in 2025

AI-Powered Irrigation: Platforms use weather

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forecasts, soil data, and satellite imagery. Saves 30-40% water and improves yields.

IoT & Soil Moisture Sensors: Affordable wireless devices now guide irrigation only when required.

Drip & Micro-Irrigation 2.0: Solar-powered, AI-integrated systems ensure uniform distribution, even in electricity-poor regions.

Smart Sprinklers: Adjust droplet size, spray angle, and timing based on wind and crop stage, reducing evaporation losses by up to 50%.

Wastewater Recycling: Solar-powered treatment units now recycle greywater for irrigation at community level.

Drones & Satellite Advisory: Multispectral cameras detect plant stress and governments send SMS irrigation alerts.

Fog Harvesting & Atmospheric Water Generators: In deserts, solar-powered devices convert humidity into irrigation water.

Blockchain for Water Credits: Farmers saving water earn tradable "credits," incentivizing conservation.

Benefits of Smart Irrigation

Efficiency: Saves 30-60% water.

Productivity: Maintains or increases yields under scarcity.

Cost Savings: Cuts electricity and fertilizer use (via fertigation).

Climate Resilience: Reduces drought impact.

Sustainability: Protects groundwater, reduces soil salinity.

Case Studies (2025)

Israel - Desert Farming: AI-driven drip + wastewater recycling = 70% less water use in vegetables.

India - Digital Krishi Villages: IoT irrigation + solar pumps = doubled water-use efficiency in Maharashtra & Telangana.

California, USA - Drought Resilience: Almond & grape growers use drone mapping + sensors → 20% higher yields, 40% less water.

Kenya - Community Smart Irrigation: Solar-powered drip + mobile pay-per-use → affordable irrigation for smallholders.

Challenges in Adoption

High Initial Cost: Small farmers struggle with affordability.

Technical Knowledge: Digital literacy & training required.

Policy Gaps: Subsidy & support often fragmented.

Connectivity Issues: Power and internet still unreliable in rural areas.

Equity Concerns: Risk of excluding marginal farmers.

The Road Ahead

To scale adoption, focus is needed on:

Affordable Technology: Low-cost sensor and drip

kits.

Capacity Building: Farmer training and digital literacy campaigns.

Policy Support: Incentives and subsidies for smart irrigation.

Renewable Integration: Solar-powered irrigation for sustainability.

Global Collaboration: Exchange of knowledge and best practices.

Conclusion

As we move deeper into the 21st century, water scarcity will shape the future of agriculture. In 2025, water-saving innovations and smart irrigation are proving to be game-changers from AI-powered drip to fog harvesting. These tools ensure that farmers can "produce more with less," securing both food and water for future generations. Smart irrigation is not merely a technological upgrade it represents a movement towards resilience, sustainability and global food security.

Geographical Indications: Driving Economic Growth in Global Agriculture

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Abstract

Geographical Indications (GIs) serve as a mark of authenticity, linking products to their place of origin and safeguarding their unique qualities. In India, 643 products as of 2023-24, including Darjeeling Tea and Basmati Rice, have GI recognition, enhancing market value, farmer income, exports, and rural livelihoods. GIs preserve cultural heritage, promote tourism, and prevent misuse of traditional names. However, challenges like limited awareness, weak branding, and global misuse persist. Strengthening promotion, legal enforcement, and digital traceability, along with educating producers and consumers, can unlock the full potential of GIs in boosting India's agricultural competitiveness and ensuring sustainable rural development in a globalized market.

Introduction

In a global marketplace flooded with mass-produced goods, consumers are increasingly seeking products with a story a connection to a specific place, a unique tradition, and an assurance of quality. This is the essence of a Geographical Indication, or GI. A GI is a sign or name that identifies a product's origin, quality, or reputation as being due to its geographical location. Protected as a form of intellectual property, GIs are a powerful tool for safeguarding the legacy of unique products and empowering the communities that produce them. India, as a member of the World Trade Organization (WTO), has a strong legal framework in place to protect these valuable assets.

The Geographical Indication of Goods (Registration and Protection) Act, 1999, which came into force on September 15, 2003, is administered by the Comptroller General of Patents, Designs and Trade Marks. This act has led to the establishment of the Geographical Indication Registry in Chennai, a pivotal step in protecting India's "invaluable treasures". The first GI system in the world, known as appellation d'origine contrôlée (AOC), was used in France in the 20th century.

GI in India

India, as a member of World Trade Organization (WTO), enacted the Geographical Indication of Goods (Registration and Protection)

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Act, 1999 has came into force with effect from 15 September 2003. The central Government has established The Geographical Indication Registry in Chennai. The GI Act is being administered by Comptroller General of Patents, Designs and Trade Marks who is the Registrar of GI. The first Geographical Indication (GI) tag in India was awarded to Darjeeling Tea in 2004. A GI registration is valid for 10 years and can be renewed for further periods of 10 years by paying a fee. If a registration is not renewed, it is liable to be removed from the register.

A Global and National Snapshot

The protection of GIs is a global effort, supported by various international agreements. These include the Paris Convention (1883), the Madrid Agreement (1891), the Lisbon Agreement (1958), and the TRIPS Agreement (1994), which was the first international treaty to protect GIs and enforce their application. Worldwide, there are approximately 65,900 GIs. The largest number of GIs can be found in Germany (15,566), followed by China (7,247), Hungary (6,683), and Italy (6,015). A product-wise breakdown shows that Wines & Spirits make up the largest category at 51.8%, while Agricultural and Food products account for 29.9% and Handicrafts for 2.7%. India currently has 643 registered GIs. A large portion of these are handicrafts, with 343 registrations (53.34%), followed by agriculture with 200 (31.10%), foodstuffs with 47 (7.31%), manufacturing with 46 (7.78%), and natural goods with 7 (0.47%).

Status of GI registration in India during 2004-05 to 2023-24

Sector/category	Number of GIs	Share in total GIs (%)	Annual average (GIs/year)
Agriculture	200	31.10	10
Food stuff	47	07.31	2
Handicraft	343	53.34	17
Manufacturing	46	07.78	2
Natural Goods	7	00.47	0
Total GIs	643	100	31

Source: The Geographical Indication Registry, MCI, GOI

Impact of GI in developing countries

Promoting products: GIs can help producers in developing countries and LDCs to promote their products, which can lead to increase sales, higher prices, and greater profitability

Creating brand equity: GIs can help producers to create brand equity, especially for those in rural areas who may not be able to invest in branding

Supporting regional development: GIs can help boost the economic development of the region where the product originated

Preventing delocalization: Geographical Indications (GIs) help protect traditional products by ensuring that large corporations cannot exploit their added value by manufacturing them outside their original region.

Preserving cultural heritage: GI can help preserve cultural heritage and encourage cultural diversity.

Increasing tourism: People who buy GI-certified products may be interested in visiting the places they come from

Benefits of GI tags

- ✓ Legal protection to the products
- ✓ Prevents unauthorized use of GI tag products by others
- ✓ It helps consumers to get quality products of desired traits and is assured of authenticity
- ✓ Promotes the economic prosperity of producers of GI tag goods by enhancing their demand in national and international markets
- ✓ Identifying fake products
- ✓ Guaranteed premium price
- ✓ Increase in export earnings
- ✓ Promotion of tourism
- ✓ Encouragement of employment
- ✓ Helps in preserving many traditional skills

The average price of Vazhakulam pineapple, after receiving a GI tag, showed a significant increase from an average price of around ₹20 per quintal in 2008 to ₹115 per quintal in 2013-14. The price fluctuated in subsequent years but remained higher than the pre-GI period this study of Kerala (Ashwathi, 2020). Price of different rice crop variety's (Gandhakasala, Palakkadan Matta, Pokkali, Kaipad, Navara and Jeerakasala) were increased after GI registration (Radhika *et al*., 2021).

India's GI Success Stories

India's GI journey is marked by several notable success stories across different product categories:

Agricultural and Food Products: Darjeeling tea was the first product in India to receive a GI tag. Other notable examples include Banganapalle and Alphonso mangoes, Nagpur oranges, and a variety of grains like Bhalia wheat, Joha rice, and Kalanamak rice.

Handicrafts and Industrial Goods: The list of protected handicrafts is extensive and includes the intricate Zari work of Surat, Sankheda Furniture, and Patan Patola from Gujarat. Other examples are Kashmir Shawls, Chanderi Sarees from Madhya Pradesh and Mysore Sandal Soap from Karnataka.

Natural Goods: Examples of GIs in this category include Makarana Marble from Rajasthan and the unique Similipal Kai Chutney from Odisha.

Some agricultural commodities are registered with GI tags that are shared by multiple states. For instance, Araku Valley Arabica Coffee is associated with both Andhra Pradesh and Odisha, while Basmati rice is linked to a total of seven states and union territories in Northern India.

The Challenge of Misuse and Awareness

Despite the legal protections, GI products, especially from India, face rampant misuse globally.

The Tea Board of India has opposed numerous instances of misuse of the term 'Darjeeling' in countries like France, Germany, and the U.S.A., where the name has been used for everything from perfumers to telecommunication services and coffee. The fight for GI protection has seen landmark legal battles. In 1997, a U.S. company, RiceTec, was granted a patent to call aromatic rice grown outside India "Basmati," a move that threatened India's trade. India successfully challenged the patent by arguing that it violated the GI rules under the TRIPS agreement, as Basmati is traditionally grown only in India and Pakistan. RiceTec subsequently withdrew its claims. Another significant case is the "biopiracy" of turmeric. In 1995, a U.S. patent was granted for using turmeric to heal wounds. The Indian Council for Scientific and Industrial Research (CSIR) challenged and successfully revoked the patent, providing evidence that the use of turmeric for medicinal purposes was a part of India's ancient and existing public knowledge. A major challenge for producers is the lack of awareness about the benefits of GIs. A study in Tamil Nadu found that producers ranked "lack of awareness about GI among producers" and "lack of awareness among consumers" as the top two reasons for the poor usage of GI tags (Niranjan *et al*., 2023).

Conclusion

GIs are a critical tool for identifying and preserving intellectual property rights related to agricultural and food items with specific geographic origins. While much has been done, including major steps taken by Indian institutions to protect cultural legacy, there is a need for appropriate promotional techniques to maximize the commercial potential of GI-tagged products. It is essential to address the lack of awareness and ensure that GI ratings are not assigned to products that are easily replicated. By doing so, GIs can continue to serve as a beacon of authenticity, quality, and heritage in a globalized world.

Future Thrust of GIs in Agriculture

- ✓ Strengthening Global Trade Competitiveness
- ✓ Promoting Sustainability and Climate Resilience
- ✓ Supporting Rural Development and Livelihoods
- ✓ Digital Transformation and Traceability
- ✓ Integrating GIs into Sustainable Tourism
- ✓ Adapting to Evolving Consumer Preferences
- ✓ Enhancing International Cooperation and Policy Harmonization
- ✓ Research and Innovation in GI Products

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Sustainable and Green Agriculture: A Path towards a Healthier Future

Megha Singh

Agriculture has long been the backbone of human survival, but the modern industrial approach to farming has brought with it several environmental, social, and economic challenges. Issues such as climate change, declining soil fertility, water scarcity, and the rapid loss of biodiversity demand an urgent transformation in the way we produce food. This has given rise to the concept of sustainable and green agriculture, which emphasizes balancing productivity with ecological and social well-being.

Understanding Sustainable and Green Agriculture

The term "sustainable agriculture" describes farming methods intended to satisfy present-day food demands without endangering the capacity of future generations to satisfy their own. Green agriculture emphasizes resource conservation and ecological harm reduction through environmentally sound practices. When combined, these two approaches create a system that protects nature while supporting farmers and communities.

Key Principles of Sustainable and Green Agriculture

Conservation of Natural Resources: Maintaining soil fertility, protecting water sources, and preserving biodiversity are essential. Methods like crop rotation, mulching, and organic nutrient management improve soil health and reduce reliance on chemicals.

Use of Eco-friendly Technologies: Renewable energy solutions such as solar irrigation systems, biogas units, and wind energy reduce dependency on fossil fuels.

Minimizing Chemical Inputs: Compost, bio-fertilizers, and integrated pest management reduce pollution while improving food quality and safety.

Climate Resilience: Practices such as agroforestry, intercropping, and rainwater harvesting enhance the adaptability of farms to extreme weather conditions.

Social and Economic Equity: Sustainable farming promotes fair incomes, strengthens local markets, and supports rural livelihoods.

Practices that Drive Green Agriculture

Organic Farming: Emphasizes natural inputs and avoids synthetic chemicals.

Agroforestry: Integrates crops, livestock, and trees to improve biodiversity and soil productivity.

Precision agriculture maximizes inputs and reduces waste by utilizing technologies such as sensors, drones, and data analytics.

Hydroponics and Vertical Farming: Innovative systems that save space and maximize production with minimal water and soil use.

Water-Saving Techniques: Rainwater harvesting

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and drip irrigation conserve water while sustaining yields.

Benefits of Sustainable and Green Agriculture

Environmental Protection: Reduces erosion, prevents water contamination and lowers greenhouse gas emissions.

Improved Food Security: Ensures the availability of safe, nutritious, and chemical-free food.

Economic Opportunities: Reduces costs for farmers and opens new markets for eco-friendly produce.

Climate Adaptation: Strengthens farming systems to withstand droughts, floods, and other climate challenges.

Challenges in Implementation

Despite its advantages, adopting sustainable methods faces hurdles such as limited farmer awareness, high initial investment, weak policy support, and restricted access to organic markets. Overcoming these challenges requires targeted government policies, farmer education, technological support, and stronger consumer demand for sustainable products.

Conclusion

The shift to sustainable and green agriculture is not optional it is essential for the survival of both people and the planet. By promoting environmentally friendly practices, empowering rural communities and encouraging responsible consumption, agriculture can evolve into a system that supports human development while preserving nature. To ensure a better future for everybody, farming's future rests in striking a balance between ecological balance and productivity.

Climate Change and Its Impact on Local Farming

Mayank Shanker

Climate change is greatly affecting how crops are grown locally. Farming has always been closely connected to the weather. Farmers rely on regular rain, stable temperatures, and predictable seasons to grow food. However, the typical farming patterns are no longer predictable due to the current rapid environmental changes. Global food production is changing as a result of the unpredict-ability of what was formerly dependable. For many local farmers, the signs of climate change are no longer something that happens far away. They see it every day. Unusual rain, longer dry periods, higher temperatures, and sudden storms are all changing how crops grow. In areas where rice used to be grown with the regular monsoon season, farmers now face either too much water that damages young plants or dry conditions that leave the soil cracked and unable to hold water. Crops like wheat, corn, and lentils are also producing less in places where they used to do well.

In regions that used to have steady rainfall, farmers used to plan their planting times with confidence. They knew the rain would come at the same time each year. But now, rain is unpredictable. In some years, heavy rain falls in a short time, causing waterlogged fields and damaged crops. In other years, the rain comes too late or not enough, which means farmers either have to wait to plant or face the risk of losing their crops. This uncertainty makes farming more dangerous than ever. Higher temperatures are also changing the way crops are grown. Wheat and other crops are particularly vulnerable to heat during the flowering and grain-forming phases. Even a slight rise of 1-2°C during these times can greatly reduce the amount of crops produced. Farmers in many places are already reporting that wheat harvests are becoming uncertain. Similarly, crops like corn and mustard that need cool winter nights are now struggling as the winters get warmer.

In parts of India, farmers are starting to replace crops that need a lot of water, like rice and sugarcane, with crops like corn, pulses, or oilseeds. Millets, once seen as food for people with less money, are becoming more popular because they can survive in dry conditions and are nutritious. This change in what's grown shows not just how farmers are adapting but also the need for policies that help this shift happen smoothly.

Another big impact is on fruit crops. Fruits like apples, which used to grow in cooler areas, are now being grown in fewer places. Apple orchards in Himachal Pradesh, for example, are now being moved to higher altitudes since the lower areas are getting too warm. On the other hand, crops like pomegranate and guava, which can handle warmer

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weather, are expanding into new areas. The change in climate also affects animals and fish. Heat stress causes cows to produce less milk, and warmer water temperatures are messing up when fish reproduce. This adds more challenges to farming families who rely on both farming and livestock for their living. Climate change is not just about the environment. It's also a big social and economic issue. Small farmers, who are the main people in agriculture in many developing countries, are especially at risk. With limited access to modern tools, irrigation systems, and crop insurance, they often face the biggest losses. This not only affects their income but also makes it harder for their communities to have enough food and good nutrition.

To deal with these problems, governments and organizations need to support farming methods that can handle climate changes. Better irrigation, growing a variety of crops, and research on crops that can handle drought or floods are very important. Reviving traditional farming knowledge, like growing different crops together and using natural ways to protect soil, also provides long-term solutions. New technology, such as weather apps, early warning systems, and mobile advice services, is helping some farmers make better choices.

However, just adapting may not be enough. There's also a growing need to reduce the emissions from farming itself. Practices like less tilling, using fertilizers more efficiently, and planting trees in farmland (agroforestry) can cut back on emissions and also help farming become more resilient.

The story of climate change and farming is really about people. It's about the farmer who looks up at the sky, worried about rain that doesn't come when it should. It's about families who have to leave their homes when crops fail again and again. It's about strength, creativity, and the effort to keep farming even when things are uncertain. As we move forward, making sure that farmers are supported and given the tools they need to adapt will be very important for keeping their livelihoods and the food security of millions of people safe.

In short, climate change is changing how farming is done. Local crop patterns are shifting, long traditions are being tested, and the future of farming is in question. Yet, even with these challenges, there are opportunities to rethink how we grow food, to invest in better ways of farming, and to support the farmers who are dealing with this crisis first-hand. The choices we make today will greatly affect not only the future of crops, but also the health, food supply, and survival of people for generations to come.

Millets: The Forgotten Superfood: Rediscovering Ancient Grains for Modern Health

Himani Chouhan

Abstract

A central to traditional farming of millet is now a superfood that is re-emerged in modern day era. These ancient grains, packed with fibre, protein, minerals, and antioxidants, contribute to better health by regulating blood sugar, improving digestion, supporting heart health, and aiding weight management. Beyond their nutritional strength, millets are hardy crops that demand little water and can grow in poor soils, making them an eco-friendly answer to global food security in the face of climate change. Once dismissed as "food of the poor," their comeback spotlighted when the United Nations named 2023 the International Year of Millets marks a worldwide shift toward healthier and more sustainable diets. Restoring millets to our plates is not only a step toward wellness but also a way to honour cultural traditions, uplift farmers, and promote sustainable agriculture for generations to come.

Introduction

Picture yourself in a sunlit field where the soil whispers resilience and the breeze shakes clusters of tiny, pearl-like seeds. These are millets humble grains that once nourished kings, farmers, and travellers, long before polished rice or hybrid wheat became staples. Each seed carries a story of survival during droughts, of nourishment passed through generations, and of grandmothers ladling millet porridge with wisdom and care. Over time, however, these resilient crops slipped into obscurity, branded as "coarse food" while processed rice and wheat filled modern markets. Today, as we confront lifestyle diseases, climate stress, and a desire to return to authenticity, millets are reclaiming their place emerging once more as nature's guardians of health and sustainability. Bringing millets back is more than a dietary choice. It is a revival of heritage, a tribute to biodiversity, and a promise of a healthier tomorrow.

Historical Roots and Cultural Significance

Older than Rice, Deeper than Time: Millets are among humanity's earliest domesticated crops, with roots stretching back more than 7,000 years. Long before rice and wheat became household staples, they sustained civilizations from the Indus Valley to African kingdoms, serving not just as food, but as lifelines in times of scarcity.

A Global Heritage, Nearly Lost Across continents, millets shaped unique food traditions from injera in Ethiopia to bajra rotis in India. Yet, during the colonial and industrial periods, refined

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grains rose in popularity, and these ancient staples were wrongly dismissed as "poor man's food." Their rich cultural and nutritional value faded into the background.

Why it still Matters?

Reviving millets is more than a dietary shift it is a reconnection with our roots, a recognition of biodiversity, and a commitment to rebuilding resilient food systems. Every millet dish prepared today is a bridge between our ancestral wisdom and our future health.

Nutritional Powerhouse

Small Grains, Big Nutrition: Don't judge them by their small size. Millets carry a powerhouse of nutrients that outshine common staples. Where polished rice delivers mostly starch and little fibre, millets step in with two times the protein and up to ten times the fibre. Finger millet (ragi) alone contains over 300 mg of calcium per 100 g, making it nature's answer to strong bones and teeth. They also excel in iron content, often triple that of wheat, helping to naturally combat anaemia and fatigue. Beyond minerals, their low glycaemic index provides slow, steady energy instead of sudden sugar spikes making them an excellent choice for those managing diabetes. In short, while rice simply fills, and wheat fuels, millets heal, protect, and strengthen. They aren't just grains for survival they're true superfoods for a healthier lifestyle.

Health Benefits & Therapeutic Potential

Food that Heals: Millets go beyond filling the plate they act as natural medicine for the body. With a low glycaemic index, they release energy slowly, making them an effective guard against diabetes and sugar fluctuations. Their rich fibre content keeps digestion smooth, reduces bloating, and supports a balanced gut. Loaded with antioxidants, these grains fight inflammation, protect the heart from cholesterol buildup, and strengthen overall immunity. Ragi, rich in calcium, helps maintain strong bones, while iron-packed bajra reduces fatigue and keeps anaemia at bay.

Wellness beyond the Body: The benefits of millets extend to the mindset of today's modern era. Millets release glucose slowly, giving the brain steady energy for better focus, stable moods, and lasting stamina. Studies show that eating them regularly can help maintain a healthy weight, improve cholesterol, and support normal blood pressure reducing the risk of lifestyle diseases.

In essence, millets aren't just survival grains they are wellness grains, helping us live with strength, clarity, and vitality.

Sustainability & Resilience

Crops that Care for the Earth: Millets are not only superfoods for people but also super crops for the planet. Where rice consumes nearly 8,000 litres of water per kilogram and wheat depends heavily on fertilizers, millets thrive with as little as 300-400 litres and flourish even in poor, dry soils. They are the farmer's safety net able to withstand drought, heatwaves, and irregular rains earning them the title of the world's most climate-smart crops.

Guardians of Soil and Water: Unlike single-crop

farming that drains natural resources, millet cultivation promotes biodiversity and eases pressure on groundwater. Bajra, foxtail, and other varieties grow without the need for chemical pesticides, protecting both soil health and farmers' well-being. For generations, communities relied on these hardy grains as lifelines during famines and scarcity, proving their unmatched resilience.

Food for the Future: In today's era of climate uncertainty, millets stand as symbols of hope nutritious for humans, sustainable for ecosystems. Every millet meal is not just food, but also a small step to help the planet.

Revival & Modern Resurgence

From Neglect to Global Stage: Once sidelined as "poor man's food," millets are now reclaiming the spotlight. The United Nations' declaration of 2023 as the International Year of Millets brought these grains back into global conversations on health and sustainability. From nutrition summits to the G20 dinner table, where barnyard millet puddings and bajra crisps were served, millets have become symbols of resilience and modern relevance.

In India Leads the Revival: The government is bringing millets back into school meals and public food programs, while farmers are proudly growing traditional millet varieties again. In other countries, cafés in New York, kitchens in Tokyo, and startups worldwide are reinventing millets into noodles, cookies, porridges, and snacks proving that these ancient grains can fit seamlessly into modern lifestyles.

A New Narrative: This resurgence is not a passing trend it's a cultural and nutritional rebirth. Millets are stepping forward as grains of the future: rich in heritage, rooted in sustainability, and essential for human well-being.

How you can Embrace Millets Today

Bringing Millets to Your Table: Embracing millets doesn't mean sacrificing flavor it means discovering wholesome food with meaning. Begin with small swaps: replace rice with foxtail or little millet once a week, or switch a few wheat rotis with bajra or jowar rotis. For breakfast, a warm bowl of ragi porridge energizes the day, while millet khichdi or dosa makes for comforting meals. Even snacks can turn healthier think millet laddus, puffed millet bites, or baked millet cookies.

A Choice that Matters: Every time you choose millets, you're not just nourishing yourself you're also supporting farmers, reviving traditions, and protecting the planet. Choose local varieties in markets, try millet dishes at restaurants, and explore new millet-based products from startups. Every mindful choice supports better health, stronger communities, and a sustainable future.

Conclusion

More than Grains, A Legacy

Millets are not relics of the past they are a living connection between ancient wisdom and modern needs. Once the backbone of civilizations, they faded under the shadow of refined staples, but today they return as the superfoods of the future: rich in nutrition, climate-smart, and deeply cultural.

Choosing millets is more than a dietary change it is an act of honouring heritage, empowering farmers, and protecting the planet. Their comeback is not a passing trend but a global movement for health and sustainability. Every small choice, whether it's a bowl of ragi porridge or a simple bajra roti, carries the power to shape a stronger, healthier tomorrow. Millets are no longer forgotten they are the future on our plates.

Zero Budget Natural Farming (ZBNF)

Mamindla Varshini

Abstract

Zero Budget Natural Farming (ZBNF) is an alternative farming approach developed in India by Subhash Palekar during the 1990s. It arose in response to the growing financial distress among farmers due to the heavy costs of chemical fertilizers, pesticides, and hybrid seeds. Unlike conventional methods, ZBNF emphasizes natural inputs, soil health, and ecological balance. The model rests on four key techniques: Jeevamrutha, Beejamrutha, Mulching, and Whapasa. Over the years, ZBNF has gained recognition in India, particularly in Andhra Pradesh, where large-scale government initiatives have supported farmer adoption. While international attention has also grown, challenges remain regarding scientific validation, scalability, and yield consistency. This paper examines the origins, philosophy, methods, reception, challenges, and future potential of ZBNF.

Introduction

Origin and Need Indian agriculture have long been the backbone of rural livelihoods. However, since the Green Revolution, reliance on chemical fertilizers, pesticides, and high-yield varieties has become widespread. While these methods increased productivity, they also led to soil degradation, declining biodiversity, rising input costs, and severe indebtedness among farmers. In this context, Subhash Palekar introduced Zero Budget Natural Farming in the 1990s. His vision was to free farmers from dependence on costly external inputs by promoting farming methods based on natural resources available within villages. The term "zero budget" highlights the possibility of farming without taking loans or incurring input costs.

Philosophy of ZBNF

The philosophy of ZBNF is rooted in the belief that nature already contains all elements necessary to sustain crop growth. Rather than fighting natural processes, farmers are encouraged to align with them. This approach views soil as a living organism and emphasizes strengthening the soil ecosystem instead of feeding crops with chemicals. In this way, ZBNF not only reduces costs but also restores ecological balance and enhances long-term sustainability.

Techniques of ZBNF

Palekar proposed four main practices that form the foundation of ZBNF:

Jeevamrutha: A liquid bio-fertilizer prepared from cow dung, cow urine, jaggery, pulse flour, and soil. It acts as a microbial booster that improves soil fertility and enhances plant growth.

Beejamrutha: A seed treatment made with natural ingredients to protect seeds from pests and promote

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better germination.

Mulching: Covering soil with crop residues or organic matter to conserve moisture, reduce weed growth, and enrich soil nutrients.

Whapasa: A principle of maintaining both moisture and air in the soil, reducing the need for excessive irrigation and preventing waterlogging.

Together, these techniques aim to create a self-sustaining agricultural system that improves productivity while lowering costs.

Reception in India

ZBNF has received significant attention in India, both from farmers and policymakers. The state of Andhra Pradesh has taken the lead by implementing a large-scale program to transition over six million farmers to ZBNF. Reports from pilot projects indicate lower input costs, improved soil health, and greater resilience to climate stress such as drought. Farmers also reported improved net incomes, even though yield levels sometimes varied compared to conventional farming. Other states like Karnataka and Himachal Pradesh have also experimented with ZBNF models.

Global Perspectives

Globally, ZBNF has been recognized as part of the broader movement toward agroecology and regenerative farming. International organizations such as the Food and Agriculture Organization (FAO) and the United Nations Environment Programme (UNEP) have highlighted ZBNF as a model of low-cost, climate-friendly farming. However, adoption outside India remains limited, and most studies are still in experimental stages. Nevertheless, its principles resonate with global concerns over sustainability, food security, and environmental protection.

Challenges

Despite positive outcomes, ZBNF faces several challenges:

Scientific validation: Critics argue that ZBNF lacks sufficient large-scale, peer-reviewed scientific evidence.

Yield concerns: Some studies suggest that while ZBNF reduces costs, yields may not always match those of conventional farming, especially for commercial cash crops.

Farmer adoption: Many farmers remain hesitant to adopt new practices due to uncertainty, lack of training, and deep-rooted reliance on chemical inputs.

Scalability: Transitioning millions of farmers requires strong institutional support, training programs, and continuous monitoring.

Prospects: The future of ZBNF depends on addressing its limitations while scaling its successes. Greater investment in scientific research, farmer education, and government support could strengthen its credibility and adoption. As climate change and resource depletion continue to challenge agriculture, ZBNF offers an alternative pathway that prioritizes sustainability, farmer well-being, and ecological balance.

Conclusion

Zero Budget Natural Farming is more than

just a set of agricultural techniques; it represents a shift in how farming is understood and practiced. By reducing input costs, restoring soil health, and aligning with natural processes, ZBNF provides a sustainable alternative to chemical-intensive agriculture. While challenges remain in terms of scientific validation, scalability, and yield consistency, the growing interest in India and abroad suggests that ZBNF has a meaningful role to play in shaping the future of farming. With continued research and support, it has the potential to balance farmer livelihoods with environmental sustainability.

Smart Packaging Technologies that Extend Shelf Life of Fruits and Vegetables

Rohit Sharma and Deepa Sharma

Abstract

The increasing consumption of fruits and vegetables, driven by population growth and healthier dietary choices, has also led to increased food waste, particularly due to their perishable nature and susceptibility to microbial spoilage. Smart packaging has emerged as an advanced solution to address these challenges by integrating sensors, active compounds and Internet of Things (IoT) connectivity to monitor and control storage conditions in real time. Active packaging systems, such as moisture absorbers, oxygen and ethylene scavengers, antimicrobial films and modified atmosphere packaging, interact directly with the food and its environment to extend shelf life and maintain quality. Intelligent packaging, including time-temperature indicators, freshness and gas sensors, RFID and QR codes, provides consumers and supply chains with accurate information on product condition and traceability. While smart packaging enhances food safety, reduces waste, improves transparency and supports sustainability, its adoption faces challenges such as high cost, technical limitations, consumer awareness gaps, recycling issues and regulatory concerns. Overall, smart packaging represents a sustainable innovation with significant potential to improve food security and minimize post-harvest losses in perishable produce.

Introduction

In recent years, fruit and vegetable consumption has increased due to population growth, healthier diets and greater awareness of nutrition. However, food waste has also become a major global issue, harming the environment, economy and public health. Fruits and vegetables, though highly nutritious are delicate and spoil quickly due to water loss, natural changes and microbial activity, which reduce their quality, taste and value. To address this, smart packaging has emerged as a modern solution. It uses advanced sensors, smart materials and Internet of things (IoT) connectivity to monitor and control temperature, humidity and gas levels in real time, keeping produce fresh longer. Earlier research (2014-2018) focused on sensors, while recent studies (2020-2024) highlight biodegradable polymers, nanocomposites and active compounds for sustainable performance.

Smart Packaging include time-temperature indicators, gas regulators and antimicrobial films, as well as RFID and QR codes for traceability. Unlike

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traditional storage methods that may affect taste, smart packaging actively responds to changes, preserving freshness, extending shelf life and reducing food waste.

Packaging: Packaging is the science, art and technology of wrapping or containing products to protect them during transportation, storage, sale and use. It also involves the process of designing, evaluating and manufacturing these containers. Think of packaging as a coordinated system that ensures goods are prepared for everything from transport and warehousing to display and final use. Its functions are broad packaging holds and safeguards products, keep them fresh, helps label and market them and ensures they reach consumers intact.

Active Packaging: Active packaging is an innovative packaging system where the package interacts with the product and its environment to modify internal conditions. Through chemical, physical or biological processes, it extends shelf life, improves safety, maintains sensory quality and preserves freshness. Unlike traditional packaging, it actively reacts with the internal atmosphere and the food itself, making it a valuable tool for quality control and sustainability in food packaging.

Moisture Absorber: Moisture absorbers are active packaging tools that control humidity using hygroscopic materials like silica gel, calcium chloride, clay or superabsorbent polymers. They prevent condensation, spoilage and lumping, keeping products such as meat, fish, bakery goods, produce and powders fresh. By reducing excess moisture, they extend shelf life, preserve quality and help reduce food waste.

Oxygen Scavengers: Oxygen scavengers remove oxygen from packages to prevent oxidation, nutrient loss, and microbial growth. Made from materials like iron powder, ascorbic acid, enzymes or fatty acids, they are used in sachets, films, labels and caps. By lowering oxygen levels, they slow respiration, extend shelf life and work effectively with Modified Atmosphere or vacuum packaging for prolonged freshness.

Ethylene Scavengers: Ethylene scavengers control excess ethylene gas that accelerates ripening and spoilage in fruits and vegetables. Made from carbon-based materials, often derived from agricultural waste, they safely adsorb ethylene without harmful by-products. Their improved efficiency through activation and modification helps extend shelf life while supporting sustainability and reducing post-harvest losses.

Antimicrobial Coatings/Films: Antimicrobial coatings are used in packaging to slow microbial growth and spoilage caused by poor handling during harvest, transport or storage. Fresh produce often carries microbes like *Escherichia coli*, lactic acid bacteria, yeasts, molds and *Pseudomonas*. These films work by releasing antimicrobial agents that maintain inhibitory concentrations against target organisms. Release can be moisture-triggered (e.g., allyl isothiocyanate from cyclodextrin). Common agents include silver-based zeolites organic acids,

bacteriocins (nisin, pediocin), lysozyme, fungicidal enzymes and compounds like triclosan**.**

Modified Atmosphere Packaging (MAP): Modified Atmosphere Packaging (MAP) changes the gas composition around food to slow metabolism and microbial growth. It uses vacuum or gas mixtures (CO_2, N_2, O_2) with suitable polymers and sealing. MAP is applied to meats, fruits, vegetables, dairy, bakery and dried foods. Risks include growth of *Clostridium botulinum*, *Escherichia coli* and *Listeria* if temperature control fails. New smart and active packaging can further monitor conditions, adjust gases and release protective compounds to improve safety and shelf life.

Intelligent Packaging

Intelligent packaging, often referred to as smart packaging, is a packaging approach that integrates advanced features to monitor the condition of products and communicate relevant information to consumers. Using technologies such as sensors, indicators and data carriers, these systems track parameters like temperature, gas composition and other quality-related factors. This helps maintain product freshness, extend shelf life, ensure safety and preserve overall quality.

Time–Temperature Indicators (TTIs): Temperature control is key to preserving food quality, safety and shelf life, aided by time-temperature indicators (TTIs) in intelligent packaging. TTIs monitor how long and at what temperatures food is stored, using chemical, enzymatic, microbial or advanced sensor-based systems. They are applied to products like fruits, vegetables and other products, with many commercial types such as Monitor Mark, Time strip and Fresh-Check. Most change color for easy consumer use and affordable, Smartphone-compatible TTIs can help cut food waste and improve shelf-life management.

Freshness Indicators: Freshness indicators in intelligent packaging are used to continuously monitor the actual freshness of food products in real time, rather than relying solely on predetermined expiration dates. By providing direct information about the product's condition, they help consumers make informed decisions about safety and edibility, thereby reducing unnecessary food disposal. These indicators detect changes in the food, such as pH shifts caused by spoilage and display visible signals often through color changes that are easy for consumers to interpret. This not only improves food safety but also plays a significant role in minimizing food waste and promoting sustainable agri-food systems.

Gas Indicators (O_2, CO_2 sensors): Indicators and sensors in intelligent packaging track gases like oxygen, carbon dioxide and ammonia to monitor food quality. Oxygen sensors detect leaks in MAP that accelerate spoilage and nutrient loss, while CO_2 sensors reveal microbial activity or spoilage during storage. These tools help ensure freshness, detect damage early and maintain food safety.

RFID Tags & QR Codes for Traceability: RFID and QR codes are key tools in food traceability, capturing product data through production, process-

ing and distribution. RFID allows automatic, contactless tracking (short or long range), while QR codes give quick access to details via Smartphone scans. Both improve transparency, enable faster recalls and connect product movement with supply chain information.

Conclusion

Smart packaging is a major innovation in the food industry, helping extend shelf life, maintain quality and ensure safety of fresh produce. Using active components (like moisture absorbers, oxygen/ ethylene scavengers, antimicrobial films, MAP) and intelligent systems (TTIs, freshness indicators, gas sensors, RFID, QR codes), it enables real-time monitoring, traceability and informed decision-making. It reduces waste, supports sustainability and improves transparency, though challenges like high costs, complexity and environmental impact remain. With ongoing research and sustainable solutions, smart packaging can become a key tool for a safer, more efficient food system.

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Why India Wastes More Food than it Exports

R. Suresh

India, one of the world's largest food producers and exporters, faces a paradoxical challenge its food wastage within the country far exceeds the volume of food it exports. According to the United Nations Food Waste Index Report 2024, Indian households alone waste approximately 78.2 million tonnes of food annually, worth an estimated ₹1.52 lakh crore (about $18-20 billion) (UNEP Food Waste Index Report, 2024). This wastage starkly contrasts with India's agricultural and processed food export value, which ranged between $37.5 billion to $48.9 billion in 2024 (APEDA, 2025). This article delves into why India wastes more food than it exports, examining the causes, economic and social consequences, and potential solutions.

Scale and Nature of Food Wastage in India

India wastes an estimated 40% of its total food production, with fruits and vegetables accounting for the highest losses of around 5-13% between harvest and retail stages (WRI India, Food Loss and Waste Report, 2021). Post-harvest losses, inadequate transportation, and poor storage infrastructure contribute significantly. India's per capita food wastage is around 55 kg annually (UNEP, 2024), with urban households wasting more due to a combination of consumer behavior and supply chain problems. In rural areas, losses primarily occur at the farm level due to lack of cold storage and inefficient supply chains, whereas in cities, waste is also generated through consumer habits such as over-purchasing and improper food management. The annual food wastage volume from households alone 78.2 million tonnes is alarmingly large, equivalent to feeding millions of food-insecure individuals across the country (PMF IAS, 2025).

Causes Underlying India's High Food Wastage

Poor Infrastructure and Supply Chains: India lacks adequate cold storage facilities and refrigerated transport systems. More than 30-40% of fruits and vegetables spoil post-harvest because of these gaps (WRI India, 2021). Climatic conditions, especially in tropical regions, accelerate spoilage, further compounding losses.

Fragmented Markets and Supply Chains: The Indian agricultural supply chain is fragmented, with many small intermediaries between farmers and consumers. This market fragmentation leads to delays, spoilage and price fluctuations that discourage farmers from timely marketing of perishable goods (Global Linker, 2017).

Lack of Awareness and Consumer Behavior: In urban areas, buying in excess, discarding leftovers, and incorrect storage cause significant waste. Cultural practices like preparing excess food during festivals and events also contribute to wastage (Dr. Reddy's Foundation, 2024).

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Inefficient Post-Harvest Management: Over 20-30% of grains and pulses are lost during storage and handling. This loss is exacerbated by pest infestation, moisture, and poor quality of storage facilities in rural areas (NABCONS, 2023).

Contrasting India's Food Export Scenario

India's food exports have steadily increased in value but remain quantitatively less than the volume wasted domestically. In 2024, agricultural and processed food exports stood at approximately $37.5 to $48.9 billion, with major commodities being rice, spices, tea, and marine products (APEDA Annual Report, 2025). For instance, rice exports reached $8.72 billion in the first nine months of FY25, showing a 19% increase YoY (DD News, 2025). However, total export quantities pale in comparison to time-bound perishable food waste and losses. The volume inequality arises because many staples and perishables prone to wastage are consumed internally or lost before marketing, not reaching export markets. Furthermore, only a fraction of total agricultural output qualifies for export due to quality, packaging, and regulatory standards, limiting quantities dispatched overseas (Vision IAS, 2024).

Economic and Social Implications

The economic cost of food wastage ₹1.52 lakh crore per year is equivalent to nearly 3.7% of India's agricultural GDP (PMF IAS, 2025). This loss drains farmer incomes and represents a missed opportunity to improve rural livelihoods through better farm-to-market linkages. Socially, the paradox of widespread food wastage amid persistent hunger and malnutrition India still has 233.9 million food-insecure people as per the Global Hunger Index 2023 raises profound ethical and policy concerns (Global Hunger Index, 2023).

Environmental sustainability is another casualty of food wastage. Producing wasted food consumes about 24% of freshwater resources and generates approximately 8-10% of global green-house gas emissions (UNEP, 2024), contributing to climate change and resource depletion.

Pathways to Mitigate Food Wastage

India's food wastage challenge requires multi-dimensional solutions, including:

Infrastructure Development: Expanding cold storage capacity, modernizing warehouses, and increasing refrigerated transport can significantly reduce post-harvest losses (WRI India, 2021).

Supply Chain Integration: Strengthening farmer-producer organizations, reducing intermediaries, and digitizing supply chains improve efficiency and reduce wastage (GlobalLinker, 2017).

Consumer Awareness Campaigns: Educating consu-mers about the impact of food waste and encouraging better purchasing and storage habits is crucial (Dr. Reddy's Foundation, 2024).

Government Policies: Supporting food processing and preservation technologies, incentivizing food donation, and implementing food waste regulations are needed (Vision IAS, 2024).

Technology and Innovation: Leveraging AI, blockchain for supply chain transparency, and cold

chain automation can optimize food distribution (WRI India, 2021).

Conclusion

India's paradox of being a major food exporter while concurrently wasting more food than it exports reveals serious systemic inefficiencies in its food supply chain. The scale of wastage 78.2 million tonnes annually worth ₹1.52 lakh crore coupled with persistent hunger and environmental impacts calls for urgent corrective measures. Agricultural students and professionals must understand this multifaceted issue to contribute effectively towards sustainable food systems. By addressing infrastructure gaps, consumer behavior, and policy loopholes, India can reduce its food wastage, enhance food security, and improve economic outcomes for millions of farmers and citizens.

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Food that Speaks: Smart Food Coating Warns You When Your Food Spoils

Gaytri Soni

The days of sniffing food or gambling on questionable leftover food may soon be over. A revolutionary technology is rolling out globally - a smart food that indicates itself when it spoils by changing its colour. These materials, which indicate spoilage in real-time, are now changing our way of thinking about food freshness and sustainability. Every year, over 1.3 billion tonnes of food-about 1/3rd of food produced are wasted globally (according to the Food and Agriculture Organisation), mostly because of food spoilage. Amid this situation, the colour-changing coating is a lifesaver for us from food wastage and spoilt food. Research is done and also ongoing at several universities (like Pusan National University, Northeastern University and National University of Singapore, etc.) that are involved across the globe to develop colour-changing food packaging and edible coatings that indicate to you when your food is no longer safe to eat.

The science behind colour-changing coating

The colour-changing coating is beyond smart visual tricks; they are carefully bioengineered layers containing food-safe material that respond to chemical and biological changes in the food leading to spoilage. These coatings are comprised of these components:

Biopolymer Film Base: The film base provides the physical matrix having colour-changing compounds in it. It must be edible or safe to eat, biodegradable and breathable.

Common film-forming biopolymers include:

Chitosan: Extracted from shellfish waste, naturally antimicrobial.

Alginate: Derived from brown seaweed; gel-forming and edible.

Gelatin: From animal collagen, transparent and stretchable.

Starch: Sourced from potato, corn, cassava.

Cellulose & derivatives: Strong, high oxygen-resistant plant-based film.

Pectin, Pullulan, Carrageenan, Agar: From various plants and seaweeds.

These films act as barriers and carriers, encapsulating food while remaining sensitive to environmental changes.

Colour-Changing Natural Indicator (Sensor)

The primary functional component is a natural dye or pigment that changes its colour in response to:

- ✓ pH changes (as food becomes more acidic or alkaline)
- ✓ Volatile amine (emitted by degrading proteins)
- ✓ Oxidation or byproduct of microbes

Most popular colour-sensitive compounds are

Anthocyanins: Extracted from red cabbage, black-

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berries, and grapes. Its colour is purple, which turns into red/yellow/green depending on the pH.

Curcumin: Obtained from turmeric. Originally the colour is yellow, which changes into orange or red according to alkaline conditions.

Betalains: Derived from beetroot. The original colour is red, which turns into yellow or brown with oxidation.

Roselle extract: Isolated from hibiscus. It is rich in anthocyanin, which is sensitive to pH.

Butterfly pea flower, black carrot and purple sweet potato: These are alternate sources of anthocyanin with vibrant transitions.

These indicators are dispersed into the coating, which changes their colour as the food environment changes.

Functional additives (Optional)

It is used to improve the performance of the coating. Scientists often use these additives for sensitivity, better response time and durability.

Essential oils: Used for antimicrobial support (e.g., oregano, thyme, clove).

Zinc oxide or silver nanoparticles: Used to enhance microbial detection or to extend shelf life

Plasticisers: Utilised for improving coating flexibility.

Mechanism of action: Why these coatings change their colour

As food items start to degrade, proteins and fats are broken down by microbes and enzymes. And simple compounds are formed, like volatile amines (ammonia, cadaverine and putrescine), organic acids CO_2 and other gases. These byproducts fluctuate the pH and environment of the food. The natural pigment present in the coating is sensitive to these changes. With changes in pH or liberated gases, the molecular structure of pigments alters, resulting in noticeable colour change. The transformation is irreversible and a threshold for microbial safety. So in short, it is not just colour change but actually indicates the actual expiry of your food or how long it is safe to eat.

Real-life use of these coatings: Colour-changing coatings are being used on several perishable foods:

Food products	Colour material	Indicator	Colour changes
Meat	Gelatin films or Chitosan	Curcumin, Anthocyanin	Purple → green/ yellow (pH rise)
Milk	Pectin coatings or pullulan	Beet extracts	Red → brown
Fruits and vegetables	Agar films or pectin	Turmeric or hibiscus	Pink → yellow
Seafood	Alginate or starch having vanillin	Anthocyanin, vanillin	Blue → colourless/ yellow
Cooked food tray	Polylactic acid	Anthocyanin	Red → green
Packaged snacks	Cellulose-based film	Butterfly pea flower	Blue → purple

Life shifting towards sustainability

Colour-changing coating shows the actual condition of the food, unlike our conventional method to analyse the life of food by expiry dates, which sometimes may not be reliable. These coatings are especially beneficial for the export of food items, monitoring while kept in cold chains and reducing food wastage at retailers or at the household level.

With time these coatings are becoming more cost-effective, highly accurate and suitable with compostable or edible packaging. The technique is a

revolutionary shift towards reducing global food wastage and giving consumers more transparency about what they are eating. As the technique is developing with time, it promises to reshape the food market and household practices worldwide.

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Biotechnology Breakthroughs: Revolutionizing Medicine and Agriculture

Nikita Patel, Hemant Bagul and R. Krishnamurthy

Biotechnology, the science of harnessing living organisms and biological systems to develop products and technologies, has emerged as one of the most transformative fields of the 21st century. Its applications span medicine, agriculture, environmental science, and industry, offering innovative solutions to some of humanity's most pressing challenges. This article explores how recent breakthroughs in biotechnology are revolutionizing medicine and agriculture, improving health outcomes, enhancing food security, and promoting sustainability.

The Promise of Biotechnology in Medicine

Gene Editing: Precision Medicine's New Frontier

One of the most groundbreaking advances in biotechnology is the development of gene editing technologies, particularly CRISPR-Cas9. Discovered in 2012 by Jennifer Doudna and Emmanuelle Charpentier, CRISPR-Cas9 allows scientists to make precise, targeted changes to the DNA of living organisms (Doudna and Charpentier, 2014). This technology has revolutionized genetic research by enabling the correction of mutations responsible for inherited diseases. Clinical trials are now underway using CRISPR to treat genetic disorders such as sickle cell disease and beta-thalassemia. In a landmark study, Frangoul *et al*. (2021) demonstrated that CRISPR-edited hematopoietic stem cells could effectively cure sickle cell disease in patients, marking a major milestone in gene therapy. Beyond inherited diseases, CRISPR is being explored to enhance cancer immunotherapy by engineering T cells to better recognize and attack tumor cells (June *et al.*, 2018).

Biopharmaceuticals: Targeted Therapies for Complex Diseases

Biotechnology has also transformed drug development through biopharmaceuticals therapeutics produced using living cells. Monoclonal antibodies (mAbs), recombinant proteins, and nucleic acid-based drugs have become essential tools in treating cancers, autoimmune diseases, and infectious diseases (Walsh, 2018). Monoclonal antibodies, for example, are engineered to bind specific antigens on cancer cells, enabling targeted destruction while sparing healthy tissue. Drugs like trastuzumab (Herceptin) have significantly improved survival rates in HER2- positive breast cancer patients (Scott *et al*., 2012). Advances in antibody engineering have enhanced their efficacy, reduced

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side effects, and extended half-life, making them more effective treatment options.

Vaccines: Rapid Response to Emerging Threats: The COVID-19 pandemic highlighted the power of biotechnology in vaccine development. Traditional vaccine platforms often require years to develop, but mRNA vaccines, such as those by Pfizer-BioNTech and Moderna, were developed and authorized within a year (Polack *et al.,* 2020). These vaccines use synthetic mRNA to instruct cells to produce the SARS-CoV-2 spike protein, eliciting a strong immune response without using live virus. This platform's flexibility allows rapid adaptation to new variants and other pathogens, revolutionizing vaccine science. Researchers are now applying mRNA technology to develop vaccines for influenza, HIV, and even certain cancers (Sahin *et al.,* 2020).

Regenerative Medicine: Repairing the Body from Within: Regenerative medicine, powered by biotechnology, aims to repair or replace damaged tissues and organs. Induced pluripotent stem cells (iPSCs), discovered by Takahashi and Yamanaka (2016), can be generated from adult cells and differentiated into various cell types, offering personalized therapeutic options without ethical concerns associated with embryonic stem cells. Applications include treating neurodegenerative diseases, heart failure, and spinal cord injuries. Tissue engineering combines cells with biomaterials to create functional tissues, potentially addressing organ shortages and improving patient outcomes.

Agricultural Biotechnology: Feeding a Growing World Sustainably

Genetically Modified Crops: Enhancing Yield and Resilience: Agricultural biotechnology has revolutionized crop production by introducing traits that improve yield, pest resistance and environmental tolerance. Genetically modified (GM) crops expressing *Bacillus thuringiensis* (Bt) toxins produce proteins toxic to specific insect pests, reducing the need for chemical insecticides (Shelton *et al*., 2002). Bt cotton and Bt corn have been widely adopted, leading to increased yields and reduced pesticide use. Herbicide-tolerant crops, such as those resistant to glyphosate, enable farmers to control weeds more effectively while practicing conser-vation tillage, which reduces soil erosion and improves soil health (Duke and Powles, 2008).

Biofortification: Combating Malnutrition: Micro-nutrient deficiencies affect billions worldwide, causing health problems such as blindness, anemia, and impaired cognitive development. Biotechnology offers solutions through biofortification enhancing the nutritional content of staple crops. Golden Rice, engineered to produce beta-carotene (a precursor of vitamin A), aims to reduce vitamin A deficiency, a leading cause of childhood blindness and mortality in developing countries (Beyer *et al*., 2002). Other biofortified crops enriched with iron, zinc, and folate are under development to address global malnutrition (Murgia *et al.,* 2012).

Climate-Resilient Crops: Adapting to a Changing Environment: Climate change poses significant threats to agriculture through increased droughts,

salinity, and temperature extremes. Biotechnology enables the development of crops with enhanced tolerance to these stresses. For example, transgenic rice expressing the DREB1A transcription factor shows improved drought tolerance by activating stress-responsive genes (Kasuga *et al.,* 1999). Salt-tolerant and heat-resistant varieties are also being developed to maintain productivity under adverse conditions (Ashraf, 2010).

Microbial Biotechnology: Sustainable Farming Practices: Microbial biotechnology contributes to sustainable agriculture by harnessing beneficial microbes. Nitrogen-fixing bacteria, traditionally associated with legumes, are being engineered to associate with cereals like rice and wheat, potentially reducing the need for synthetic nitrogen fertilizers (Mus *et al.,* 2016). This innovation could lower greenhouse gas emissions and production costs, promoting environmentally friendly farming.

Ethical, Environmental and Regulatory Challenges: While biotechnology offers tremendous benefits, it also raises ethical, environmental, and social concerns. Gene editing in humans, especially germline modifications, prompts debates about safety, consent, and potential misuse (Baltimore *et al.*, 2015). Off-target effects and long-term consequences remain areas of active research. In agriculture, concerns include gene flow from GM crops to wild relatives, impacts on biodiversity, and socio-economic effects on smallholder farmers (Nicolia *et al.,* 2014). Public acceptance varies globally, influenced by cultural, ethical and regulatory factors. Robust regulatory frameworks are essential to ensure safety and build public trust. International organizations such as the World Health Organization (WHO) and Food and Agriculture Organization (FAO) advocate for transparent, science-based policies that balance innovation with precaution (WHO, 2014).

The Future of Biotechnology: Integration and Innovation

The future of biotechnology lies in integrating emerging technologies such as artificial intelligence (AI), machine learning, and synthetic biology. AI can accelerate drug discovery, optimize gene editing, and improve crop breeding by analyzing vast datasets (Ching *et al.,* 2018). Synthetic biology enables the design of novel biological systems and organisms with customized functions, opening new possibilities in medicine, agriculture, and environmental remediation. As biotechnology continues to evolve, interdisciplinary collaboration, ethical stewardship, and inclusive dialogue will be critical to harness its full potential for the benefit of humanity and the planet.

Conclusion

Biotechnology breakthroughs are revolutionizing medicine and agriculture by providing precise tools to treat genetic diseases, develop targeted therapies, improve crop yields, and promote sustainability. From CRISPR gene editing and mRNA vaccines to genetically modified and biofortified crops, these innovations address critical health and food security challenges. While ethical and regulat-

ory considerations remain, responsible research and governance can ensure that biotechnology's promise is realized safely and equitably. As we advance into the future, biotechnology stands as a beacon of hope, offering transformative solutions to improve quality of life and sustain our planet.

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Smart Farming with Plastics: Balancing benefits and Risks in Agriculture and Allied Sectors

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Introduction

Plastics have silently entered almost every farm. From mulching films spread across vegetable fields to drip irrigation pipes and greenhouse covers, they are reshaping modern agriculture. Farmers today rely on plastics to save water, reduce weeds, and boost yields. For instance, mulching sheets help the soil stay moist and warm, allowing crops like tomatoes, chillies, and cucumbers to grow faster. Similarly, plastic-based drip and sprinkler systems ensure that every drop of water reaches the plant roots, cutting down wastage. Plastics have become inseparable from modern farming and allied sectors. From mulching films in crop fields to silage bags in dairies, from fish tanks in aquaculture to feeders in poultry farms, plastics are improving efficiency, reducing losses, and helping farmers earn better incomes. At the same time, careless disposal of plastics is creating long-term challenges for soil, water, and the environment. In late 2021, FAO released a landmark report assessing the use of plastics in agriculture. The report calculated that, in 2019, agricultural value chains used 12.5 million tonnes of plastic products in plant and animal production and 37.3 million tonnes in food packaging. Agricultural soils are one of the primary receptors of plastics and are known to contain larger quantities of plastic particles than oceans, especially in urban areas. Several studies have reported that plastics cannot be entirely avoided in agriculture, but their wastes can be managed by the Refuse, Reduce, Redesign, Reuse, Recycle, and Recover model that can reduce the flow of plastic pollutants in agricultural settings (Imran Ali Lakhiar, 2024).

Plastic particles enter the soil in different ways. They may result from the breakdown of agricultural plastics such as containers, mulch films, silage wraps, and greenhouse covers. They can also come from products already contaminated with plastics, such as compost or sewage sludge. These microplastics often originate in wastewater treatment plants, where they are carried in from sources like washing of synthetic clothes or the wear and tear of vehicle tyres. Once in the soil, plastics can exist in different sizes: macroplastics (larger than 5 mm), microplastics (smaller than 5 mm) and nanoplastics (smaller than 1 µm) (GESAMP, 2019).

Benefits Farmers see

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Agriculture: Higher Yields with Plastics

Mulching films: Retain soil moisture, suppress weeds, and improve yields in vegetables.

Drip and sprinkler irrigation: Plastic pipes ensure water efficiency.

Greenhouses & nurseries: Transparent sheets, trays, and seedling bags help protected cultivation.

Storage & marketing: Plastic crates, bins, and packaging reduce post-harvest losses.

Dairy & Animal Husbandry: Clean and Efficient Farming

Silage bags: Store fodder safely for livestock.

Milk handling: From milk cans to pouches, plastics ensure hygiene and easy transport.

Water troughs & feeders: Lightweight, durable plastic containers for animals.

Fisheries & Aquaculture: Plastics Supporting Blue Revolutio

Fish tanks, cages, and nets: Durable and cost-effective.

Aeration pipes and tubs: Support better fish health and water quality.

Ice boxes & packaging: Maintain freshness during transport.

Poultry and Beekeeping: Plastics in Small-Scale Sectors

Poultry: Plastic feeders, drinkers, and housing parts improve hygiene and reduce disease.

Beekeeping: Frames, containers, and packaging help in honey production and marketing.

The Hidden Challenges

But plastics are not without problems. Old mulching sheets and irrigation pipes often remain in the soil, where they slowly break down into tiny microplastics. These particles harm soil health, reduce fertility, and may even enter the food chain. Worse still, burning plastics in fields releases toxic gases, polluting the air and affecting both people and livestock.

Microplastic Pollution in Soil & Water

- ✓ Thin mulching films and irrigation pipes break down into microplastics.
- ✓ These tiny particles reduce soil fertility, harm beneficial microbes, and can enter the food chain

Impact on Animal Health

- ✓ Cattle often consume leftover plastic bags and silage covers, leading to digestive problems or even death.
- ✓ Poultry sometimes peck on plastic litter, affecting feed intake.

Water Body Pollution

- ✓ Discarded fishnets and cages in aquaculture release plastics into rivers and ponds.
- ✓ These harm aquatic life and contribute to “ghost fishing.”

Greenhouse Gas Emissions

- ✓ Open burning of plastic waste in fields or near dairies releases toxic gases like dioxins and furans.
- ✓ These are harmful to farmers, livestock, and the environment.

Waste Management Gap

- ✓ Most rural areas lack proper collection or recycling facilities for agricultural plastics.

- ✓ Farmers often dump or burn plastic waste due to lack of awareness and alternatives.

Dependence on Non-Biodegradable Products

- ✓ Farmers rely heavily on cheap plastic products since biodegradable alternatives are expensive and less available.
- ✓ This increases long-term pollution risks.

Soil and Water Quality Decline

- ✓ Continuous use of non-degradable plastics may gradually degrade soil structure and contaminate groundwater.

Recycling of plastic

Protects soil and water: Prevents microplastic contamination.

Reduces pollution: Avoids toxic gases from burning.

Saves costs: Recycled plastics can be used again in farming.

Supports circular economy: Waste is turned into useful products.

How Recycling Works in Agriculture

Collection at Farm Level

- ✓ Farmers gather used mulching films, plastic bags, drip lines, and crates instead of leaving them in the field.
- ✓ Collection centres or cooperatives can help in bulk storage.

Cleaning and Sorting

- ✓ Plastics are washed to remove soil, fertilizers, or pesticide residues.
- ✓ Sorted into types (LDPE, HDPE, PP, etc.) for proper recycling.

Recycling Process

- ✓ Plastics are shredded, melted, and re-moulded.
- ✓ Recycled materials are used to make new irrigation pipes, crates, nursery trays, and even road-laying materials.

Biodegradable Alternatives

- ✓ Some companies are now producing biodegradable mulching films that decompose naturally in soil.
- ✓ Though costlier, these reduce the burden of collection and recycling.

The Way Forward

Awareness for Farmers: Educate on collection and safe disposal.

Village-level Recycling Units: Set up small recycling plants near farming clusters.

Government Incentives: Provide support for recycling initiatives, subsidies for biodegradable plastics, and strict rules against burning plastics.

Public-Private Partnerships: Encourage industries to take back used plastics from farmers for recycling.

Conclusion

Recycling of plastics in agriculture is not just about waste management it is about protecting the soil, ensuring clean air, and creating a sustainable future for farmers. With proper systems in place, plastics can move from being a challenge to becoming an opportunity, turning farm waste into wealth.

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Algae-Based Biofuels: A Sustainable Alternative to Fossil Fuels

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Abstract

Algae-based biofuels have emerged as a promising renewable energy source capable of addressing the depletion of fossil fuels and reducing greenhouse gas emissions. Microalgae, owing to their high lipid content, rapid growth and ability to thrive in non-arable land using wastewater and CO_2 emissions, are considered ideal feedstocks for biofuel production. Advances in genetic engineering, biorefinery techniques and integration with carbon capture technologies have boosted the potential of algal biofuels. Despite these innovations, challenges such as optimizing biomass yield, reducing production costs and scaling up biotechnologies remain. Continued research and technological development are essential to realize algae-based biofuels as a scalable, economically viable alternative to fossil fuels within the next decade.

Introduction

Global fossil fuel reserves are depleting rapidly due to increasing population and energy demands. Fossil fuels, which supply about 80% of global energy and 99% of chemical feedstocks, contribute significantly to greenhouse gas emissions, air pollution and global warming, leading to ecological imbalances and health risks (Mahmood *et al*., 2023).

Fossil fuels, coal, oil and natural gas currently fulfill around 80% of global energy needs and supply 99% of chemical feedstocks used in industry. However, these finite resources are rapidly depleting due to increasing population, industrialization, and energy consumption. If present usage continues, oil reserves could be exhausted by 2052. Additionally, fossil fuel combustion releases substantial carbon dioxide and other greenhouse gases, intensifying climate change. This leads to global warming and extreme weather events, threatening ecosystems, human health, agriculture, water security and economic stability. In light of these concerns, there is an urgent need for cleaner, renewable energy alternatives. Algal biofuel has emerged as a promising solution. Algae convert atmospheric CO_2 into biomass through photosynthesis, which can be processed into biocrude a petroleum-like fuel compatible with existing refineries. Although technically feasible, algal biofuel faces challenges in scaling up, primarily due to low

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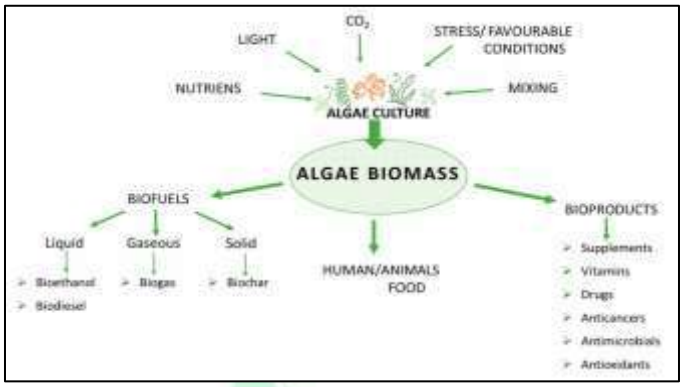
biomass yields in outdoor cultivation systems. To compete with fossil fuels, algal biomass output must improve by at least 36%. Achieving this requires progress in strain engineering, cultivation methods and biorefinery integration. With focused innovation and policy support, algal biofuel can become a vital part of the sustainable energy transition (Ruffing *et al*., 2022).

What are Algae-Based Biofuels?

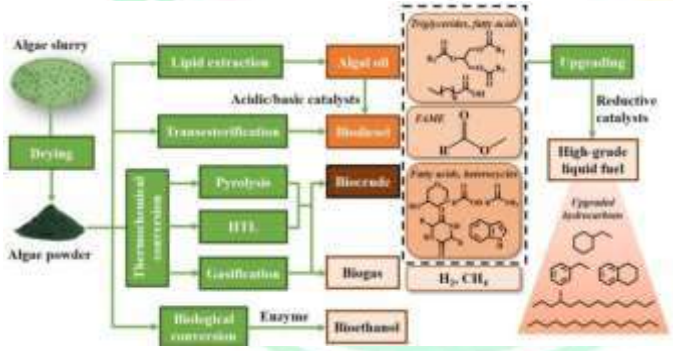
Algae-based biofuels are sustainable fuels produced from algal biomass through various conversion processes, leveraging algae's oil-rich composition lipids, polysaccharides, fatty acids, pigments, antioxidants and minerals derived from efficient photosynthesis, making them versatile feedstocks for biodiesel, bioethanol, biohydrogen and biobutanol to replace fossil fuels in transportation and industry. Algae, photosynthetic autotrophs inhabiting aquatic environments, exist as single cells, colonies or filamentous forms, with nearly 300,000 known species found in seawater, freshwater and wastewater; they are simpler than plants, lacking true roots, stems, and leaves (Bhateria and Dhaka, 2014). Classified into macroalgae (seaweeds) and microalgae, the latter are particularly valuable for biofuel production due to high lipid yields, ease of year-round cultivation without arable land or freshwater, non-edibility, CO_2 absorption and wastewater treatment benefits. Biofuel production involves cultivating microalgae in open ponds or closed bioreactors, harvesting biomass via centri-fugation or filtration and extracting lipids for biodiesel through transesterification, or processing biomass via biochemical (fermentation) or thermochemical (pyrolysis, liquefaction, gasification) methods to produce ethanol, methane, bio-oil or syngas, which are refined.



Algal biomass production and use of an obtained algal biomass in different industry branches (Zhou and Hu, 2020)

How Algae Become Fuel: Open pond systems, particularly raceway ponds, are the oldest and simplest methods for large-scale microalgae cultivation. These shallow, oval-shaped ponds use paddlewheels to circulate algae, nutrients, and water in a continuous loop. Constructed with concrete or plastic-lined earth, they are shallow (15-35 cm) to ensure sunlight exposure, with sizes ranging from 0.2 to 0.5 hectares. Water and nutrients are constantly fed in, while algae-rich water is harvested from the other end. Algae farms utilize waste CO_2, maintaining pH and physical conditions for high CO_2 absorption efficiency. Productivity depends on surface area and is often limited by contamination from other microorganisms or unwanted algal strains. Photobioreactors are enclosed systems used to grow algae efficiently while also performing tasks like removing pollutants from wastewater or flue

gases. Unlike open ponds, they offer a controlled environment, minimizing contamination and allowing higher biomass concentration and faster harvesting. Common designs include tubular, flat-plate, helical coil, rectangular and stirred tank reactors. Tubular reactors use transparent tubes to maximize light exposure, while flat-plate designs offer high photosynthetic efficiency. Hybrid systems combine photobioreactors with open ponds, using bioreactor-grown inoculums to reduce contamination risks. Despite higher infrastructure and energy costs, photobioreactors are essential for high-yield algal biofuel production, especially in areas with limited land and water resources.



Schematic diagram for conversion of algae into biofuel (Jablonska-Trypuc *et al.*, 2023)

The sustainability of algae-based biofuel largely depends on the oil extraction process, which is costly. Algae are first harvested and then oil is extracted using mechanical or chemical methods. Mechanical methods like expression press and ultrasonic extraction require dry algae, making them energy-intensive. Chemical methods such as hexane, Soxhlet and supercritical fluid extraction pose safety and environmental risks. Enzymatic extraction, though effective, is expensive. Osmotic shock is another technique that ruptures algal cells in solution to release oil and cellular contents (Baskar *et al.*, 2018).

Environmental and Economic Benefits: As global oil supplies decline, algae-based biofuels are gaining attention as a sustainable alternative. Algae grow rapidly, are eco-friendly, non-edible and thrive in varied environments. They absorb CO_2, release oxygen and help prevent pollution. Their biofuel production uses only blue water, avoiding rainwater use and minimizing pollution-related water consumption. Worldwide, CO_2 is mainly obtained in liquid form for ease of storage and transport, often from ammonia production or flue gases via the MEA (mono ethanolamine) process. It can also be injected into algal ponds near emission sources. Using nutrient-rich wastewater for algae cultivation reduces environmental impact and supports both growth and treatment. (Collotta *et al.*, 2018) Co-products play a crucial role in improving the economic feasibility of algae-based biofuels by creating additional income sources. High-value compounds like proteins, enzymes and pharmaceuticals increase profitability, especially when biofuels alone are not viable. Utilizing residual biomass for co-products lowers costs, reduces financial risk and attracts investment, enhancing competitiveness.

Challenges on the Road Ahead: Commercializing algae biofuels faces several key challenges, including the need to identify and enhance algal strains with high lipid yields, resilience and minimal

nutrient requirements. Most strains produce limited oil, necessitating advanced genetic engineering and bioprospecting. Cost-effective cultivation, harvesting and lipid extraction methods are essential to lower production costs. Scaling up from lab to industry adds technical and environmental hurdles. Proper nutrient recycling, co-product development, and energy efficiency are also vital for economic viability. Environmental impacts and high costs currently limit large-scale adoption.

Recent Innovations and Breakthroughs: Recent advancements in algae biotechnology include genetic engineering, AI integration and carbon capture applications. Engineered algae strains now exhibit improved lipid content, growth and resilience, enhancing biofuel and bioproduct yields. Synthetic biology is also customizing metabolic pathways to produce valuable compounds. Artificial intelligence and machine learning optimize cultivation conditions, strain selection and scale-up processes, thereby improving efficiency and reducing costs. Additionally, integrating algae systems with carbon capture technologies allows the use of industrial CO_2 emissions, as algae can absorb around 2 kg of CO_2 kg^{-1} of biomass. These breakthroughs support sustainable, scalable and economically viable algae-based biorefineries within a circular bioeconomy (Samoraj *et al.*, 2024).

Conclusion

Algae-derived biofuels offer promising sustainable energy, but commercial viability depends on improving biomass yields, process efficiency and cost effectiveness. With advancements in genetic engineering, cultivation, harvesting and CO_2 capture plus waste utilization supported by research and policy, scalable algae biofuels could soon become competitive.

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Green Revolution

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Introduction

Green hydrogen, produced using renewable energy sources and emitting no greenhouse gases, is rapidly gaining traction as a cornerstone of clean energy strategies around the globe. Among its most promising and sustainable production pathways is the conversion of agricultural waste an abundant and underutilized resource into green hydrogen. This approach not only offers a carbon-neutral or even carbon-negative fuel but also provides an effective solution for agricultural waste management, supports rural economies, and fosters energy self-sufficiency.

The Rationale: Agricultural Waste as a Resource

Agriculture generates tremendous volumes of byproducts, including crop residues (stalks, husks, straw), animal manure, and food processing waste. Traditionally, much of this material is either left to decompose (releasing methane and other potent greenhouse gases) or burned, contributing to local air pollution and climate change. By channeling this biomass into green hydrogen production, these environmental challenges are addressed while simultaneously creating value from what was formerly considered waste.

Conversion Pathways: Biological and Thermochemical Processes

Biological Methods

Anaerobic Digestion and Fermentation: In this process, microorganisms break down organic matter in the absence of oxygen. Through dark fermentation, certain strains of bacteria such as Clostridium spp. and Enterobacter spp. directly convert carbohydrates contained in agricultural waste into hydrogen, carbon dioxide, and organic acids. In photo-fermentation, photosynthetic bacteria further convert organic acids into hydrogen in the presence of light, thus boosting overall yield.

Pretreatment and Enzymatic Hydrolysis: Since agricultural residues are structurally complex (lignocellulosic), they are typically pretreated mechanically, chemically, or biologically to increase the accessibility of fermentable sugars. Enzymes such as cellulases and hemicellulases are then used to hydrolyze these complex carbohydrates, making them digestible for hydrogen-producing microbes.

Thermochemical Methods

Gasification: This involves reacting the biomass at high temperatures with limited oxygen or steam, converting complex organic molecules into a hydrogen-rich syngas (a mixture primarily of hydrogen, carbon monoxide, and carbon dioxide). Advanced catalysts and sorbents are increasingly used to maximize hydrogen yield and purity, while capturing undesirable byproducts.

Pyrolysis and Hydrothermal Liquefaction: Pyrolysis converts agricultural residue into biochar

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and hydrogen-rich gases under controlled high temperatures without oxygen. Hydrothermal liquefaction, meanwhile, processes wet biomass using heat and pressure, making it suitable for feedstocks with high moisture content. Recent research highlights hybrid approaches that combine biological and thermochemical techniques for improved overall efficiency and scalability.

Recent Innovations and Case Studies

Cutting-edge research institutions have made significant progress in recent years. For example, scientists at the Indian Institute of Science (IISc), Bengaluru, recently developed a technology capable of producing 99% pure hydrogen from agricultural waste, demonstrating an output of 5 kilograms per batch with high efficiency. Such breakthroughs showcase the rapid advancement and growing commercialization potential of these methods.

Furthermore, new methods leverage renewable electricity (such as solar or wind power), in tandem with biochar derived from agricultural byproducts, to dramatically reduce the energy input required for water electrolysis the process by which hydrogen is separated from water molecules. These integrated systems can cut the electricity demand for hydrogen production by up to 600%, making hydrogen not only cleaner but also cost-competitive with conventional fuels.

Environmental and Societal Benefits

Greenhouse Gas Reduction: Utilizing agricultural waste for hydrogen production avoids methane and carbon dioxide emissions from biomass decomposition or open burning, offering a truly low-carbon fuel alternative.

Rural Employment and Circular Economy: As green hydrogen facilities are typically located close to their biomass feedstock, they foster rural economic development and create jobs across the supply chain from waste collection and preprocessing to energy production and distribution.

Landfill Diversion and Pollution Control: Converting agricultural waste into high-value products like green hydrogen minimizes landfill usage and prevents leachate and emission problems associated with unmanaged waste.

Energy Security and Decentralization: By utilizing local biomass resources, regions and nations can reduce dependence on imported fossil fuels, moving closer to energy independence and resilience.

Key Challenges and Future Outlook

Despite its promise, several obstacles remain:

Feedstock Variability: The composition and availability of agricultural waste can vary by region and season, potentially affecting the consistency and scalability of hydrogen production.

High Pretreatment Costs: The technical complexity and cost of pretreating lignocellulosic feedstocks remain hurdles for commercial viability.

Capital and Operational Costs: Large-scale facilities require significant upfront investment, access to renewable electricity, and robust logistics for biomass collection and handling. Ongoing research aims to address these issues through impro-

ved catalysts, optimized processing conditions, and the use of artificial intelligence for process control and feedstock management. Policy incentives, investment in bio-refineries, and life-cycle environmental assessments will be crucial for mainstream adoption.

Conclusion

Green hydrogen from agricultural waste stands at the intersection of clean energy innovation, sustainable agriculture, and climate action. By harnessing what was once an environmental problem, this approach unlocks a carbon-neutral fuel source, generates rural economic opportunity, and sets the stage for a circular, resilient, and sustainable future. As technology matures and supportive policies accelerate deployment, green hydrogen from agricultural residues is poised to become a pillar of the global energy transition.

Bee Vectoring and Nature based Pest Control

Akhand Pratap Singh

What is Bee Vectoring?

Bee vectoring technology (BVT) employs commercially managed bees, such as honey bees or bumblebees, equipped with special dispensers inside their hives containing organic biopesticide powders. As bees leave their hives to forage, the powder adheres to their bodies, allowing them to deliver targeted doses of pest- and disease-controlling agents directly to the flowers they pollinate. This precise delivery system leverages natural bee behavior to both pollinate and protect crops all at once, making it a smart, eco-friendly dual-purpose tool for farmers.

How does Bee Vectoring Work?

The bees pass through a dispenser in their hive that coats their bodies with a fine powder containing microorganisms such as beneficial fungi or bacteria. Common biopesticides used include Beauveria bassiana, a fungus that parasitizes many insect pests. As the bees visit flowers often making thousands of trips daily they spread the powder evenly across the plants. This biological agent then colonizes the plant surface or tissues to:

- ✓ Suppress or outcompete harmful fungal pathogens (e.g., Botrytis or Sclerotinia).
- ✓ Attack or inhibit insect pests like thrips, aphids, and whiteflies
- ✓ Stimulate natural plant defenses for increased resilience.

Benefits of Bee Vectoring Technology

Environmental Advantages: Unlike chemical pesticides, bee vectoring uses natural and non-toxic agents that do not harm bees or beneficial insects. It drastically reduces chemical runoff, soil contamination and pollution, supporting healthier soil microbiomes and ecosystems.

Improved Crop Yields and Quality: This targeted biological control helps reduce pest and disease damage, leading to healthier plants and higher yields with better fruit quality. Studies have reported crop yield increases of up to 29% attributed to the combined effects of enhanced pollination and pest control.

Water and Resource Conservation: Traditional pesticide sprays often consume large volumes of water and can cause drift or runoff; bee vectoring requires no water for application, reducing resource use and environmental risk.

Economic and Social Benefits: By protecting crops more sustainably, farmers can reduce costs associated with chemical pesticides and improve profitability. Supporting pollinator populations also benefits overall crop biodiversity and farm resilience.

Crops Benefiting from Bee Vectoring

Bee vectoring has shown effective pest and disease control across multiple crops, including:

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- ✓ Berries: Strawberries, blueberries and raspberries
- ✓ Apples and other orchard fruits
- ✓ Sunflowers
- ✓ Greenhouse tomatoes
- ✓ Canola and other seed crops

The technology is versatile and adaptable to diverse agroecosystems that depend heavily on pollination and face pest pressures.

Comparison with Traditional Pest Control

Aspect	Comparison
Application	Bee Vectoring: Targeted delivery to flowers by bees Traditional: Broad spraying, soil application
Chemical Usage	Bee Vectoring: Minimal, using biological agents Traditional: High amounts, synthetic broad-spectrum
Environmental Impact	Bee Vectoring: Minimal, supports pollinator and ecosystem health Traditional: Pollution, off-target toxicity
Pollination Support	Bee Vectoring: Enhances pollination as a natural benefit Traditional: Often harmful to pollinators
Crop Yield Impact	Bee Vectoring: Up to 29% increase due to pollination & control Traditional: Variable, less sustainable
Water Use	Bee Vectoring: None Traditional: High, especially in spray applications
Residue on Crops	Bee Vectoring: Minimal or none Traditional: May leave chemical residues

Challenges and Future Prospects

While promising, bee vectoring faces challenges such as:

- ✓ Scaling production of biopesticides and ensuring consistent delivery
- ✓ Maintaining bee health amid other environmental threats
- ✓ Regulatory approvals and adoption hurdles in conventional farming

Ongoing research focuses on optimizing formulations, dispenser designs, and exploring new microbial agents. Policy support and farmer education will be critical to broad adoption.

Conclusion

Bee vectoring technology exemplifies the future of eco-friendly pest control by harnessing nature's best pollinators as partners in crop protection. By integrating pest management directly into pollination, this innovation supports sustainable food production that benefits farmers, ecosystems, and consumers alike. As global agriculture seeks to reduce chemical dependencies, bee vectoring offers a powerful, natural solution blending biotechnology and ecological harmony.

Rainfed Sugarcane Cultivation

N. Sabitha

Sugarcane cultivated under limited/ deficient water availability or drought situation crop is affected by water stress condition at any stage of growth. Sugarcane juice quality is greatly dependant on availability of water supply. Depending on crop growth stage the effect of water stress condition is accounted.

In sugarcane cultivation if water stress condition is realized in the tillering stage or early growth stages then it is effected by decrease in the production of tillers, nodes and node development. In delayed planting situation, water scarcity effects the tillering capacity, grand growth stage, maturity stages as well resulting in density of nodes per plant and also reduced sugar recovery. Under drought / water scarcity conditions due to prevailing high temperatures and transpiration losses crop is affected by different pests and diseases. It reduces cop yield by 30-50%. The farmers can expect good crop harvest and profitable returns by adopting certain simple and feasible practices to overcome drought or water scarcity condition. They are:

Mulching: Older dried leaves present at bottom can be pulled and spread on ground in between the rows of sugarcane crop. This acts as mulch and helps to reduce evaporation loss of water. Similarly leaf matter obtained after harvest of plant crop and ratoon crop can be utilized for mulching plant crop at 3-30 days after planting and immediately after ratooning in the ratoon crop at the rate of three ton per hectare. This technique prevents evaporation loss of water from soil and control weeds, and reduces attack of early shoot borer. Mulching practice will enhance soil to maintain moderate temperature and provides suitable microclimate for sugarcane growth. This also increases the germination percentage, number of nodes there by higher cane yield. In the ratoon crop mulching helps in formation new tillers from stubbles, and increased tiller growth.Sugarcane dried leaf waste if applied near roots of sugarcane plant followed by earthing up provides organic manure to the crop in the later stages of growth.

Irrigation to skipped row: Under water scarcity conditions irrigation may be given to alternate plant rows. The row which is not irrigated can be covered with mulch. By following this remedial measure under drought situation we can save upto 50% of total irrigation water. This also increases water use efficiency.

Foliar spray: Under drought situation due to unavailability of nutrients and difficulty in the nutrient uptake foliar spray of nutrients is highly recommended. Urea and murate of potash together are sprayed at the rate of 2.5 kg dissolved in 100 litre of water twice at 15 days interval. Hand sprayer can be used in early stages of crop. Spraying should be

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done before 11.00 am and after 3.00 pm. Avoid foliar spraying in the afternoon hours since stomata will be closed in the afternoon and plant cannot absorb nutrients. Also avoid foliar spraying during heavy winds. Terpal can be mixed with nutrient solution that acts as an additive to improve spray liquid retention and penetration on crops.

While cultivating sugarcane under water scarcity or drought situation farmers must choose specific varieties suitable for growing under water scarcity or drought situation. Also dipping of sugarcane setts in lime water and deep row planting also prevents damage to sugarcane crop under limited water conditions and secures optimum cane yields. Therefore, by following above said techniques farmers can reap profits in sugarcane cultivation under drought situation.

The Next Frontier in Gene Editing: NLR-Based Systems Could Revolutionize Medicine and Agriculture

Nitesh Kushwaha, Kanchan Kumari Gupta, Digvijay Singh, Tushar Arun Mohanty and Prem Chand Gyani

Abstract

The recent discovery of NLR-based gene editing systems marks a groundbreaking advancement in genetic engineering. Inspired by the immune systems of plants, these systems utilize engineered NLR (Nucleotide-Binding Leucine-Rich Repeat) proteins to achieve precise and programmable DNA editing. Unlike CRISPR-Cas9, which relies on guide RNA for targeting, NLR-based systems leverage customizable protein domains, potentially offering higher specificity and reduced off-target effects. This innovation addresses key limitations of CRISPR, such as RNA dependency and unintended edits, while expanding the scope of gene-editing applications. NLR-based tools hold immense promise for treating genetic disorders, developing disease-resistant crops, advancing biotechnology research, and supporting environmental conservation. However, challenges remain, including optimizing efficiency, improving delivery mechanisms, and addressing ethical concerns. As research progresses, NLR-based gene editing systems could revolutionize medicine, agriculture, and beyond, ushering in a new era of precision genetic engineering**.** In the world of science, few breakthroughs have captured the public's imagination like CRISPR-Cas9, the gene-editing tool that has revolutionized genetic engineering over the past decade. But just as we were getting comfortable with CRISPR, scientists have unveiled a groundbreaking new gene-editing technology that could take precision genetic manipulation to the next level. Enter NLR-based gene editing systems, a novel approach inspired by the immune systems of plants. Discovered in late 2023, this technology promises to address some of CRISPR's limitations while opening up exciting new possibilities in medicine, agriculture, and beyond.

What are NLR-Based Gene Editing Systems?

NLR (Nucleotide-Binding Leucine-Rich Repeat) proteins are naturally occurring molecules found in plants, where they play a critical role in the

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immune system. These proteins detect invading pathogens, such as bacteria or viruses, and trigger a defense response to protect the plant. Scientists have now repurposed these proteins to create a programmmable gene-editing tool that can target and modify DNA with remarkable precision. Unlike CRISPR, which relies on a combination of guide RNA and the Cas9 protein to locate and cut specific DNA sequences, NLR-based systems use custom-izable protein domains to recognize and edit genetic material. This unique mechanism allows for highly specific targeting, potentially reducing the risk of off-target effects a common concern with CRISPR.

How Does It Work?

The NLR-based system works in three key steps:

Target Recognition: The engineered NLR proteins are designed to recognize specific DNA sequences. This is achieved by modifying the protein's binding domains to match the target gene.

DNA Editing: Once the NLR protein binds to the target DNA, it introduces precise changes, such as cutting the DNA strand or inserting new genetic material.

Cellular Repair: The cell's natural repair mechanisms take over, incorporating the desired changes into the genome.

This process is similar to CRISPR in its goal but differs in its execution. By using proteins instead of RNA for targeting, NLR-based systems offer a new level of flexibility and precision.

Advantages over CRISPR

While CRISPR has been a game-changer, it's not without its limitations. NLR-based gene editing systems could address some of these challenges:

Reduced Off-Target Effects: One of the biggest concerns with CRISPR is the potential for unintended edits in non-targeted regions of the genome. Early studies suggest that NLR-based systems may offer greater specificity, minimizing these risks.

No RNA Dependency: CRISPR relies on guide RNA to locate target DNA, which can complicate delivery mechanisms, especially in therapeutic applications. NLR-based systems eliminate this dependency, potentially simplifying the process.

Versatility: NLR proteins can be engineered to target a wider range of genetic sequences, making them a more versatile tool for researchers and clinicians.

Potential Applications

The discovery of NLR-based gene editing systems has sparked excitement across multiple fields. Here are some of the most promising applications:

Medicine: Treating Genetic Disorders: NLR-based systems could revolutionize the treatment of genetic diseases, such as sickle cell anemia, cystic fibrosis, and muscular dystrophy. By precisely correcting faulty genes, this technology offers hope for long-lasting or even permanent cures.

Agriculture: Developing Resilient Crops: In agriculture, NLR-based systems could be used to create crops with enhanced resistance to diseases, pests, and environmental stressors like drought or extreme temperatures. This could help address food

security challenges in a changing climate.

Biotechnology: Advancing Research: For scientists studying gene function and regulation, NLR-based tools provide a powerful new way to explore the genome. Their precision and versatility could accelerate discoveries in fields ranging from cancer biology to neuroscience.

Environmental Conservation: NLR-based systems could also play a role in conservation efforts, such as editing the genes of endangered species to improve their resilience or combat diseases.

Challenges and Ethical Considerations

While the potential of NLR-based gene editing is immense, there are still hurdles to overcome:

Optimizing Efficiency: The technology is in its early stages, and researchers are still working to improve its efficiency and reliability.

Delivery Mechanisms: Getting NLR proteins into target cells, especially in living organisms, remains a challenge.

Ethical Concerns: As with any gene-editing technology, there are ethical questions to consider, particularly when it comes to editing human embryos or making irreversible changes to ecosystems.

What's Next?

The discovery of NLR-based gene editing systems is a testament to the power of scientific innovation. While it will take time to fully develop and refine this technology, the possibilities are truly exciting. Researchers are already exploring ways to optimize NLR-based tools and expand their applications. In the coming years, we can expect to see more studies demonstrating the potential of NLR-based systems in both laboratory and real-world settings. As the technology matures, it could become a cornerstone of genetic engineering, complementing or even surpassing CRISPR in certain applications.

Conclusion

The unveiling of NLR-based gene editing systems marks a new chapter in the story of genetic engineering. By harnessing the power of plant immune proteins, scientists have created a tool that could overcome some of CRISPR's limitations and open up new frontiers in medicine, agriculture, and beyond. While challenges remain, the potential of this technology is undeniable. As we stand on the brink of this new era, one thing is clear: the future of gene editing is brighter and more precise than ever before. Whether it's curing genetic diseases, developing resilient crops, or unlocking the secrets of the genome, NLR-based systems are poised to play a leading role in shaping the world of tomorrow.

Soil Solarization: A Sustainable Approach to Soil Health

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Abstract

Soil solarization is an environmentally friendly, non-chemical method for controlling soil borne pathogens, pests and weeds through solar heat. This technique involves covering moist soil with transparent polyethylene sheets during the hottest months, allowing solar radiation to elevate soil temperatures to levels lethal to many soil-dwelling organisms. The process improves soil health, enhances crop yields and reduces reliance on chemical pesticides. As global agriculture shifts toward sustainable practices, soil solarization emerges as a practical solution for small to medium scale farms.

Introduction

Soil health is fundamental to agricultural productivity and sustainability. Among the many challenges facing farmers today are soil borne pathogens, pests and invasive weeds that hinder crop yields. Conventional solutions often rely on chemical fumigants and synthetic pesticides, which can have adverse environmental and human health impacts. In light of these concerns, there has been a growing interest in sustainable and non-chemical methods of soil management. One such technique is soil solarization a process that harnesses the natural energy of the sun to disinfect the soil. Soil solarization is performed by covering moist soil with transparent polyethylene sheets for 4 to 8 weeks during the hottest time of the year.

Solar radiation heats the soil beneath the plastic, raising temperatures to levels that are lethal for many soils borne fungi, bacteria, nematodes and weed seeds. The effectiveness of the method depends on factors such as temperature, duration, soil moisture and the type of polyethylene used. First introduced in the 1970s, soil solarization has gained attention not only for its efficacy but also for its compatibility with organic farming systems.

Fig. 1: Plastic cover soil

Fig. 2: Soil Solarization

It improves soil structure and microbial balance, often resulting in increased crop vigor and yield. The method is especially useful in tropical and

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subtropical regions where high summer temperatures make solarization most effective.

Benefits of Soil Solarization

Control of Soilborne Pathogens and Pests: Soil solarization effectively controls a wide range of harmful organisms including fungi (e.g., *Fusarium*, *Pythium*), bacteria (e.g., *Ralstonia solanacearum*), and nematodes. High soil temperatures (often exceeding 45-50°C) disrupt the life cycles of these pathogens, reducing their populations significantly. Studies have shown solarization can reduce disease incidence by over 80% in certain crops.

Weed Management: Weed seeds and seedlings are particularly sensitive to heat. Solarization kills seeds before they germinate, leading to a noticeable decline in weed pressure during the growing season. This is especially beneficial in organic farming systems, where chemical herbicides are not allowed.

Enhanced Soil Fertility: The heating process accelerates the breakdown of organic matter and increases the availability of nutrients such as nitrogen, phosphorus, and calcium. This nutrient release can enhance crop growth even in the absence of added fertilizers. Additionally, beneficial microorganisms often recolonize the soil quickly, promoting a balanced microbial community.

Improved Crop Yields: By reducing competition from weeds and the damage caused by pathogens and pests, crops grown in solarized soils often exhibit increased vigor and higher yields. Research indicates that yield improvements can range from 10-50% depending on the crop and environmental conditions.

Environmental and Economic Sustainability: Unlike chemical fumigation, soil solarization does not introduce toxic substances into the environment. It minimizes the need for chemical inputs, reduces labor for weeding, and is cost-effective, especially in regions with high solar intensity. It can be an excellent alternative for smallholder farmers with limited access to agricultural chemicals.

Integration with Other Methods: Soil solarization can be integrated with other eco-friendly practices like organic amendments, biological control agents, and cover cropping. Such integrated approaches further enhance soil health and pest suppression while building long-term resilience in farming systems.

Conclusion

Soil solarization presents a sustainable, low-cost solution for managing soilborne pests, pathogens and weeds. Its benefits extend beyond pest control to include enhanced soil fertility, improved crop yields and reduced environmental impact. This method is particularly well-suited for small and organic farms in sunny climates. As agricultural practices move toward greater sustainability, soil solarization stands out as a practical and effective strategy. Continued research and farmer education will further improve its adoption and adaptation to diverse farming systems, supporting global efforts for eco-friendly food production.

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An Effective Soil Activator: Jeevamrut

S. L. Bankar, R. S. Hange and M. A. Ajabe

Abstract

Jeevamrut is a liquid organic manure which is an excellent source of natural carbon and biomass that contains macro and micro nutrients required by crops. In comparison to other forms of manures, Jeevamrut has proven to be more effective and can be used along with other manures. The product of organic liquid fertilizer is meant for the fermentation process, which constitutes efficient living soil microorganism that improves the plant growth, productivity and supply sufficient amount of nutrients. Such fertilizers are cost effective and eco-friendly bio-inoculants having great potential to enhance agricultural production in a sustainable way. It can reduce excessive use of the chemical fertilizers in the soil which cause low fertility of the soil. Therefore, Jeevamrut is the best alternative to chemical fertilizer. Jeevamrut, a natural fertilizer, is prepared by fermenting a mixture of cow dung, cow urine, jaggery, pulse flour, and soil. The process involves combining these ingredients, allowing them to ferment, and then diluting the mixture before application to plants.

Introduction

Jeevamrut is completely organic and has no negative impact on soil health. It consists of the terms "Jeevan" and "Amrit." Both are derived from Sanskrit words. The first word is Jeevan, which means "Life," and the second term is "Amrit", which means "Medicinal potion." Jeevamrut is an unique Indian bio-pesticide and organic manure produced through a unique fermentation procedure that combines cow dung, urine, jaggery, pulse flour, soil, and water. Jeevamrut is moderate green in colour with mild foul odour and with progression in storage period it attains darker in colour with strong foul odour. According to agricultural view, Jeevamrut is for crop life. It is the best culture to increase the count of microorganisms. Jeevamrut, is a microbial culture, mainly prepared from cow dung and cow urine generally used in organic farming to meet the nutritional requirement of crops.

Preparation of Liquid Jeevamrut

- ✓ Take 200 liter of water in barrel.
- ✓ Take 10 kg local cow dung (Indian breed) and 5-10 liter cow urine (Gomutra) and add it in water.
- ✓ Add 2 kg jaggery (Gud), 2 kg pulses flour and handful soil from the bund of the farm in barrel.
- ✓ Then stir the solution well and keep it for 48 hours in the shadow. The mixture needs to be stirred couple of times for minimum 10 minutes.

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It gets fermented. After 48 hours Jeevamrut is ready to use. It can be used for 2-3 days.

- ✓ After 8 days of preparation, bacteria start reducing which are present in liquid jeevamrut.

Preparation of GhanJeevamrut

- ✓ Take 100 kg of local cow dung (Indian breed), 2 kg of jaggery, 2 kg of pulses flour, handful soil from the bund of the farm.
- ✓ Mix it by adding small amount of cow urine (Gomutra).
- ✓ Spread it in shadow for drying.
- ✓ After drying make its powder by hand. Ghanjeevamrut is ready to use.

Application of Jeevamrut

In liquid Form: Spray 5-10% of Jeevamrut in water. For acre, 100-200 l lit. of jeevamrut is needed. It is beneficial if it can used once at interval of 7-10 days.

In Solid Form (Ghanjeevamrut): Spread directly to field. It can be used for 6-8 months.

Beneficial Effects of Jeevamrut on Crops

- ✓ Increased plant growth
- ✓ Increased palatability
- ✓ Increased sustainable crop productivity and profitability
- ✓ Increases nutrient content and uptake by crop Increased quality of produce
- ✓ Increased nutrient use efficiency, energy
- ✓ Use efficiency, water productivity and
- ✓ Resource use efficiency

Advantages of Jeevamrut

- ✓ Acts as an agent to increase the microbial count & friendly bacteria in the soil.
- ✓ Improves pH of the soil.
- ✓ Jeevamrut can be made within 4-5 days so it can be used effectively and frequently.
- ✓ Suitable for all crops and increases the yield.
- ✓ Reduces costs of chemical fertilizers.

Conclusion

Jeevamrut is low cost liquid organic manure which is an excellent source of natural carbon, beneficial micro-organism such as nitrogen fixing and phosphate solubilizing bacteria, macro and micro nutrients which is efficiently used between 8th and 12th days of preparation. Thus, the use of Jeevamrut is the best alternative organic source of nutrients instead of chemical fertilizer and better bio enhancer to improve the fertility status of soil and increase the sustainable crop productivity, quality, profitability, nutrient use efficiency and resources use efficiency. Jeevamrut is beneficial for soil, plant as well as ecofriendly.

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Smart Farms, Smart Future: Technology in Modern Agriculture

Mahendra Kumar Seemar, Jitandra Yadav, Saroj and Sarita Choudhary

Abstract

Modern agriculture is changing as a result of the quick development of technology. By combining digital tools like IoT, AI, robotics, and big data analytics, smart farming is helping farmers make more accurate, effective, and sustainable decisions. This article looks at the main elements of smart farming, such as automation, data-driven tactics, and precision agriculture, and how these developments are tackling issues like resource scarcity, food security, and climate change. Agriculture is changing into a more resilient and ecologically friendly sector that is ready to satisfy the demands of coming generations by implementing these technologies.

Introduction

Agriculture has been the backbone of human civilization for thousands of years, sustaining societies and forming cultures. However, the increasing population expansion, declining arable land, water scarcity, climate change, and labor shortages present farmers with hitherto unheard-of difficulties. Despite being based on expertise and handed down through the centuries, traditional farming methods are no longer enough on their own. Here in lies the role of smart farming. This contemporary method, often referred to as precision agriculture, makes use of cutting-edge technologies, including robotics, big data, artificial intelligence (AI), and the Internet of Things (IoT), to maximize every step of the farming process. Farmers can make better decisions, cut waste, boost output, and support sustainability by using technology into agriculture. A more effective, data-driven, and ecologically responsible food production system is the end result an essential step toward feeding a future population expected to exceed 9 billion by 2050.

Characteristics of Modern Farming

The Rise of Smart Farming

In agricultural production systems, smart farming incorporates information and communication technology (ICT) into sensors, machinery, and equipment. The objective is to increase crop yield and quality while lowering resource waste and human labor.

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Modern farms now frequently use technologies like satellite imagery, artificial intelligence (AI), the Internet of Things (IoT), and GPS-based soil mapping. Farmers may use these tools to automate time-consuming tasks, make data-driven choices, and track the health of their crops and soil in real time.

Precision Agriculture: Precision agriculture, which employs technology and comprehensive data to customize farming operations to the unique characteristics of a field down to individual plants in certain situations is at the core of smart farming. In contrast, entire fields are frequently treated equally in traditional farming.

Precision farming depends on

GIS and GPS Mapping: To examine crop yields, soil composition, and field topography, farmers utilize GIS (Geographic Information Systems) and GPS-enabled tractors. This makes it possible to apply inputs like water, fertilizer, and insecticides at different rates.

Drones and satellite imaging: Compared to manual examination, aerial imagery is significantly more reliable in predicting production, monitoring crop health, and detecting plant stress.

Weather and Soil Sensors: These sensors give farmers access to real-time data on weather, pH levels, and soil moisture, allowing them to irrigate or fertilize only when and where necessary.

Remote sensing: One of the most important technologies in contemporary agriculture and smart farming is remote sensing. It entails gathering information about the surface of the Earth without making physical touch, usually with the use of satellites, drones, or airplanes fitted with sensors.

Drone based farming and screening of crop

Robotics and Automation on the Farm: Agriculture has been mechanized for more than a century, but smart farming uses automation and robots to go a step further. These days, tasks that were formerly completed by human labor may be completed by robots and AI-powered devices often more quickly, correctly, and without becoming tired.

Important technologies consist of

Autonomous Tractors: With little human supervision, these GPS-guided tractors can plant, harvest, and plow crops.

Harvesting Robots: For delicate crops, particularly in situations where manual labor is expensive or in short supply, machines such as robotic grape harvesters and strawberry pickers are being utilized more and more.

Automated Irrigation Systems: Smart irrigation systems avoid overwatering or under watering by using sensor data to precisely water crops when necessary.

Livestock monitoring: Farmers are notified in real time of any symptoms of disease by wearable techno-

logy that tracks the productivity, activity, and health of cows and other animals.

Uses of Robot in farming system

Data and AI: The Brain behind the Operation

Data is the lifeblood of smart farming. Large volumes of data are produced by each sensor, drone, and automated device. Farmers are using big data analytics and artificial intelligence (AI) to make sense of it all.

AI is changing decision-making in the following ways

Predictive analytics: AI can predict anything from the best times to plant to crop illnesses and insect outbreaks by examining historical patterns and present circumstances.

Crop management platforms: These computer programs compile information from several sources and give farmers useful information on when to fertilize, harvest, or irrigate.

Market Optimization: Farmers may make more informed judgments about what to cultivate and when to sell by using AI to predict market demand and pricing changes.

Climate-Smart Tools: Farmers can better prepare for extreme weather conditions by using machine learning algorithms that anticipate future climate conditions.

Sustainability and the Future of Farming

Sustainability is becoming more and more necessary since the globe is under pressure to produce more food with fewer resources. In addition to increasing output, smart farming greatly lessens the environmental impact of agriculture.

Among the long-term advantages of smart farming are

Effective Water Use: When compared to conventional systems, precision irrigation can save up to 50% of water.

Decreased Chemical Use: Applying fertilizer and pesticides at the right location minimizes runoff and soil deterioration.

Reduced Carbon Emissions: Reduced greenhouse gas emissions are a result of resource optimization and autonomous electric machinery.

Urban Agriculture: By lowering transportation costs and permitting year-round growing, controlled environment agriculture (CEA) techniques like hydroponics and vertical farming bring food production closer to consumers.

Summary

“Smart Farms, Smart Future: Technology in Modern Agriculture” focuses on how new technology are making farming more sustainable, accurate, and efficient. Key advancements that assist farmers make better decisions and maximize resource use are covered in the article, including robots, automation, artificial intelligence, and precision agriculture. Additionally, it highlights how

data analytics are used in sustainability, crop management, and forecasting. A secure and sustainable future for agriculture is ensured by smart farming, which provides potential methods to produce more with less as global issues like food poverty and climate change worsen.

Fish Preservation Methods

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Abstract

Fish preservation is critical to maintaining food security, reducing post-harvest losses, and ensuring the availability of high-quality seafood products globally. Due to its high perishability, fish undergoes rapid spoilage through biochemical (enzymatic autolysis), microbial, and oxidative processes, leading to significant economic and nutritional losses. This review comprehensively examines both traditional and modern fish preservation techniques, highlighting their mechanisms, advantages, and limitations. Traditional methods such as salting, drying, smoking, fermentation, and canning have been widely used for centuries, offering cost-effective solutions but often facing challenges related to quality retention and safety. Modern technologies, including high-pressure processing (HPP), pulsed electric fields (PEF), irradiation, ultrasound, and super chilling, provide advanced alternatives that enhance shelf life while preserving nutritional and sensory attributes. Emerging innovations such as intelligent packaging, micro fluidization, and microwave processing further demonstrate the potential for sustainable and efficient preservation. The review emphasizes the need for optimized preservation strategies that balance effectiveness, energy efficiency, and minimal environmental impact. By integrating traditional knowledge with cutting-edge technologies, the seafood industry can mitigate spoilage, improve food safety, and meet the growing global demand for high-quality fish products. Future research should focus on green technologies, reduced chemical dependency, and improved cold chain logistics to ensure long-term sustainability in fish preservation.

Introduction

The world's population is constantly increasing and in order to preserve food's nutritional value, texture, and flavour while extending its shelf life, it must be stored and transported from one location to another. Therefore, effective food preservation methods must stop food from spoiling due to microbes without compromising its nutritional value or quality. Microbial, enzymatic, and chemical processes can all cause food products to deteriorate. A quarter of gross primary agricultural and fisheries goods are lost each year due to microbiological spoiling and chemical deterioration (Baird-Parker, 2000). Thirty percent of landing products are lost due to microbial activity alone. Every year, over 4-5 million tonnes of trawled and prawn fish are lost to microbiological and enzymatic spoiling brought on by improper storage.

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Fish that has just been caught can deteriorate very rapidly. In the high ambient temperatures of the tropics, the spoiling process (Rigour mortis) starts within 12 hours of capture (Berkel *et al*., 2004). The phenomenon known as rigour mortis occurs when muscles in fish stiffen up soon after death, causing them to lose their suppleness. The majority of fish species deteriorate as a result of oxidation, micro-biological spoiling from surface bacteria, and digestive enzymes and lipases (AMEC, 2003). Fish deterioration involves the breakdown of several components and the formation of new molecules. The changes in the fish meat's flavour, texture, and odour are caused by these novel chemicals. This presents a significant concern regarding the freshness of marketable products and the breakdown of proteins and lipids. Energy-intensive freeze-storage preservation can be supplemented with synthetic or natural preservatives to manage lipid oxidation and microbial growth in fish during storage. The use of a combination of these preservatives along with refrigeration reduces the spoilage process.

Fish Preservation Techniques

Various preservation methods like drying, smoking, freezing, chilling, brining, fermentation and canning are noted to prolong the shelf life of seafood and meat products. Nonetheless, low-temperature storage and chemical methods for regulating water activity as well as for controlling enzymatic, oxidative and microbial soilage are the most preavalent in today's industry (Akinola *et al*., 2006; Berket *et al*., 2004).

Traditional techniques of Seafood products preservation

Salting: Salting is an economical and natural technique commonly utilized in the food sector. Its functions include ensuring microbiological safety, enhancing sensory characteristics, particularly color, (salty) taste, and texture, as well as serving as a binding and emulsifying agent. It is well-established that 1. 5-2. 0% NaCl guarantees the sensory appeal of canned or cooked seafood items. For instance, Jiang *et al*. examined the physicochemical and microstructural mechanisms influencing quality changes in lightly salted tilapia (*Oreochromis niloticus*) fillets during frozen storage. The improve-ment of tilapia fillet quality was noted through a light salting process, and it was found that these conditions could affect the storage stability of frozen fillets during preparation. Furthermore, fermented and salted fish (FSF), such as freekeh, moha, and renga, are highly favored in Egypt; during various social gatherings and celebrations, fish-based dishes take center stage as main courses. Although they are widely enjoyed, these dishes present notable health risks, including both biological and chemical hazards. These hazards stem from possible contaminants in fish tissues, which pose a risk of transmitting food-borne illnesses, such as botulism intoxication, to consumers. Applying a Hazard Analysis Critical Control Point (HACCP) system acts as a preventive approach to guarantee the

safety of fish-based dishes and protect consumers.

Canning: Canning, when performed accurately, is an essential and safe method for food preservation. This technique involves prepping food, sealing it in sanitized jars or cans, and then boiling the containers to destroy or reduce any remaining bacteria. Since foods vary in their natural resistance to spoilage, the final step may necessitate using a pressure cooker. Jars or other containers are heated to eliminate bacteria responsible for food spoilage. The heating process expels air from the jar, and as it cools, a vacuum seal is created. This vacuum seal prevents air from entering the product, which could otherwise introduce microorganisms that contaminate it. Food can be safely processed with either a boiling water bath or a pressure canner. The procedure consists of cooking the food, sealing it in sterilized jars or cans, and boiling the containers for sterilization. Any remaining microbes are killed or weakened in these conditions. Once a jar or can has been opened, food preserved by canning or bottling is immediately vulnerable to spoilage. Water or microorganisms could infiltrate during the canning process due to inadequate quality control. Most of these failures are quickly detected as spoilage in the can generates gas, leading the can to swell or rupture. However, there have been instances where inadequate manufacturing and hygiene allowed the obligate "anaerobe" Clostridium botulinum to infect canned food, leading to the production of a potent toxin that causes severe illness or death. Canned foods can significantly contribute to sodium intake in the diet. Excessive salt increases the risk of health issues, including high blood pressure.

Chilling: Chilling referes to the technique of lowering the temperature of fish or fish products to a level close to the freezing point of ice. This cooling method prolongs shelf life by slowing down physical and chemical reactions, while also impeding the activey of spoilage microorganisms and enzymes. Chilled fish retains outstanding sensory qualities, making it very attractive to consumers. However, it may encounter possible microbial safety issue within the temperature range where it is stored as psychotropic pathogens are able to thrive and reproduce without causing immediate sensory alterations. Chilling effectively minimize spoilage in fish if performed quickly and if the fish are kept cool and managed carefully and hygienically. Rapid chilling of fish guarantees high-quality products. The key chilling techniques for fish and fish products at non-freezing temperatures are 1- Iced storage, 2- Chilled seawater (CSW) storage, 3- Chilled freshwater (CFW) storage, 4- Mechanically Refrigerated seawater (RSW) storage, and 5- Cold air storage. Ice slurries, or flow ice. Due to their enhanced heat exchange capability, these water-ice systems can reach temperatures below zero more swiftly, safeguarding the fish oxidation and dehydration. In addition, ice slurries consist of more spherical parti-

cles than flakes, which results in reduced physical damage. Various additives to the fish, as well as to the ice slurry, have been used to increase the efficiency of these ice slurries. Examples of these substances include natural antioxidants, ozone and combinations of organic acids.

Freezing: Taking into account the existing value chain, freezing occurs on vessels and upon arriving at the processing facility, either as freezing fresh fish on board or, more commonly, following thawing and processing (double freezing) prior to transport to the marketplace. Freezing constitutes 62% of processed foods, with India being the fourth-largest exporter of seafood, primarily in its frozen state. In the modern food industry, freezing practice has been solidly established as a highly effective preservation method for extending the shelf life of various food items. Freezing hinders the biological, chemical, and physical deterioration of food as well as the decline of food quality (color, texture, lipid oxidation, enzymatic activity). Quality degradation in frozen fish has been linked to protein denaturation, which has a strong correlation with the loss of sensory quality. Freezing may negatively influence the structural and chemical properties of muscle. The quicker and more uniform the freezing process, the smaller the ice crystals formed, resulting in less textural damage to muscle fibres Slow freezing can lead to the formation of larger ice crystals, which can damage cell membranes and elevate the risk of oxidation, texture deterioration, and reduction of water-holding capacity. During the storage of frozen fish, maintaining a stable temperature is crucial to prevent the formation of ice crystals. Furthermore, some researchers, including Dawson *et al.*, discovered that fatty acid (C16:1) levels decrease in meat fat during frozen storage, while polyunsaturated fatty acids (PUFAs) showed no decline.

Fermentation: Fermentation is one of the oldest methods of food preservation. Today, this technique is utilized to produce a wide variety of food items in households, small food enterprises and large corporations.

Additionally, fermentation represents a cost-effective means of food preservation that holds economic significance for developing countries. This method employs natural microbes or antimicrobials to preserve food and enhance its shelf life. During this process, beneficial bacteria or fermentation products are utilized to regulate and inhibit microorganism growth. Indeed, carbohydrates are converted into alcohol or organic acids by employing yeasts or bacteria under anaerobic conditions. All other attributes, such as flavor and texture, result from the activity of lactic acid bacteria. Products can be preserved in this manner year-round. Fermented foods are exceptionally popular worldwide as flavourful, nutritious, and healthy components of our meals. They utilize a diverse array of ingredients and production techniques to manufacture them on a large scale.

Super chilling: Super chilling, also known as partial freezing or deep chilling, is characterized by the use

of extremely low temperatures situated between regular chilling and freezing. This method entails reducing the temperature by 1-2 °C below the original freezing point of the food item. The super chilling technique turns a small fraction of water (5-30%) into ice, which forms a thin film (1-3 mm) on the surface of the food. Along with an internal ice reservoir. As a result, the combined influence of low temperature and both internal and external ice on food production slows down deteriorative processes (such as microbial activity), and for brief periods, ice might not be necessary during transport or storage. Ideally, in super chilling, a minimal amount of water content is converted into ice. Consequently, there is reduced freezing-induced protein and structural harm (separations and breaks of myofibers) caused by ice crystals in comparison to frozen storage. The shelf-life of super food can be one and a half to four times longer relative to the chilling process owing to the decrease in microbial and enzymatic activity.

Drying: Drying is among the oldest and most commonly used food preservation techniques. It involves the decrease of water content, which slows down microbial or enzymatic degradation processes and thereby prolongs shelf life and deters food spoilage. Furthermore, the volume and weight of the food diminish during the drying process, leading to reductions in food packaging size, facilitating easier transportation and reducing storage costs. Conversely, the drying procedure significantly affects the final product's quality, which is contingent on the physical and biochemical transformations that occur during this process. The alterations in the food matrix are heavily influenced by variables such as drying duration, temperature, and the product's water activity. If the drying method is improper or inadequate, the quality of the dried food or agricultural products will not meet the required standards for market introduction. In certain instances, the inefficient drying process can result in loss of food flavor, darkening of the final product's color, or moisture gradients within the dried food. Therefore, the quality of the final product is largely determined by the methodology employed. Typically, processes that utilize lower temperatures (like freeze-drying) necessitate extended drying times; therefore, high-temperature drying methods are more extensive, although this could jeopardize quality. Consequently, the food industry is confronted with the challenge of achieving shorter drying periods while maintaining moderate conditions and maximizing quality.

Frying: One of the well-liked and economical methods of food preservation is frying. Fried foods have an extended shelf life, and the flavors are also improved. Conversely, using unsuitable frying oil could pose health risks to consumers. Standard fried foods generally possess a vibrant color, a crunchy texture,

and a delightful flavor. In fact, fried meals are unhealthy due to their high oil, calorie, and acrylamide content. Innovative frying methods need to be developed to minimize oil absorption during frying and create healthier fried options with reduced oil. This technique represents the easiest and quickest method of processing fish, like Mackerel. As one of the oldest food preparation techniques, it provides benefits like simplicity, rapidity, and cost-effectiveness. Fried foods remain a primary choice in our diets today. Consumers of all ages prefer them for their favorable nutritional content and unique organoleptic traits, which encompass flavor, color, texture, and aroma. Numerous chemical and physical transformations occur during the frying process, including starch gelatinization, protein denaturation, water evaporation, and the formation of the crispy fried exterior. It can kill bacteria, deactivate enzymes, and reduce food's ability to hold water.

Smoking: Smoking is a commonly accepted technique for processing fish in Europe, Africa, and the Far East, where smoked fish and meat are

enjoyed as culinary treats. This ancient preservation method combines the effects of salting, drying, heating, and smoking to improve the flavour and longevity of the fish. The smoking procedure requires exposing the fish to fire. Smoked seafood is divided into two categories based on processing temperature: cold-smoked or hot-smoked. Cold-smoked items are processed at temperatures below 33◦C, categorizing them as minimally processed. A traditional cold smoking process entails salting, drying, and ultimately, smoking. The main goal of salting is to reduce the water activity (aw) to prevent spoilage factors, which can occur through dry, brine, or injection salting methods. A further decrease in aw happens during the drying and smoking phases. Cold-smoked seafood is quite prone to deterioration, and sensory evaluations indicate a limited shelf life of 3-5 weeks when kept at 4◦C. The spoilage of cold-smoked products is mainly attributed to off-Flavors arising from microbial growth and metabolism.

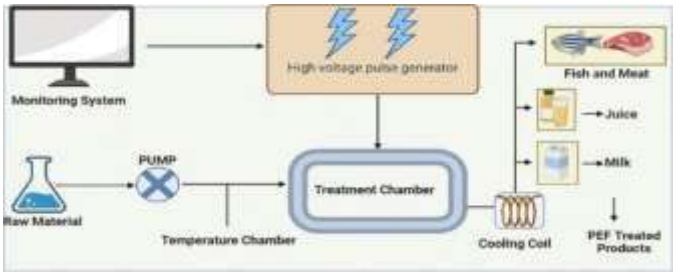
Modern techniques for Seafood products preservation

At present, research continues on novel technologies and preservation methods aimed at reducing the impact on the nutritional value of food products. In this context, we will succinctly explore modern techniques for seafood product preservation.

Microwave processing: Microwaves represent a type of electromagnetic radiation with wavelengths that vary from one millimeter to one meter, positioning them as a viable substitute for traditional heating techniques. In the related literature, micro-wave heating is frequently identified as dielectric heating due to the absorption of waves by materials possessing dielectric characteristics. These materials known as dielectrics, maintain a relatively high specific resistance along with low electrical conductivity. Furthermore, the molecules or atoms that constitute the dielectric (such as agri-food items) display dipole movement. Microwave technology is

extensively utilized within the food sector. It is employed for various purposes, including cooking, drying, thawing, pasteurization, or sterilization of food items, with most households owning a compact microwave. Microwave drying also is used to remove moisture from fish and fishery products. Microwave combined with other drying methods, such as air drying, vacuum drying, or freeze drying, gave better drying characteristics compared to their respective drying methods or microwave drying alone (Chandrasekaran *et al.*, 2013).

Pulsed Electric Field (PEF): Pulsed Electric Field (PEF) processing is a non-thermal technique used for preserving food primarily aimed at inactivating microbes. It is also applied in extraction, drying, and several mass transfer operations. PEF processing can enhance the shelf-life of food, sustain high nutritional value, and retain acceptable sensory characteristics. This method includes the use of brief pulses (1-100 s) within strong electric fields (0. 3-4 kV cm^{-1}) and is gaining traction in seafood treatments and preservation. PEF (pulsed electric field) treatment provides numerous benefits compared to heat treatments. It effectively eliminates pathogens from unprocessed food items without compromising their nutrient integrity and flavour. PEF is frequently employed in the treatment of liquid and semi-solid food blends, as well as in the extraction of food ingredients. This technique can also deactivate parasites and lower the moisture levels of tissue, thereby reducing ice crystal formation and freeze damage in frozen products.



PEF can improve the extraction of valuable nutritional components from fish processing by-products, while safeguarding physicochemical properties and achieving favourable organoleptic attributes along-side nutrient and vitamin levels in the end product. The PEF treatment additionally makes fish flesh more porous and enhances its ability to retain water. Furthermore, it can function as an effective pretreatment step for drying fish, as evidenced by Klonowski *et al*. in 2006. Besides these benefits, PEF has proven to be a swift and effective approach for extracting chondroitin sulphate from fish bones. This approach not only reduces waste but also diminishes the potential environmental hazards associated with chondroitin extraction techniques.

High Pressure Processing (HPP): High Pressure Processing (HPP) is a non-thermal pasteurization technique, particularly suitable for liquid foods and highly perishable products. This process entails exposing foods to extremely high pressures (vessel pressure between 300 and 800 MPa) for a short time, effectively eradicating microorganisms.

This technology is especially relevant in contemporary food processing industries where high-temperature treatments are not necessary for food preservation. HPP-treated food must be packaged and contain water, then sealed in a chamber where the pressure is gradually increased. It is sealed in a chamber where the pressure rises. Depending on the food type, the treatment lasts from several seconds to 20 minutes. A study was performed to assess the effects of HPP treatments on key vegetative bacteria in specific foods. The findings indicated that HPP is a safe pasteurization technology capable of decreasing major food bacterial pathogens by at least 5 logs (*E. coli, S. enteritidis,* L. monocytogenes, Vibrio, and *Staphylococcus aureus*), without the use of heat.

Conclusion

Food preservation is essential to meet the demands of a growing global population, ensuring food safety, extending shelf life, and maintaining nutritional quality, texture, and flavour. Fish, being highly perishable, undergoes rapid spoilage due to microbial activity, enzymatic reactions, and oxidation. Traditional preservation methods such as salting, canning, chilling, freezing, fermentation, super chilling, drying, frying, and smoking have been widely used to mitigate spoilage and enhance shelf life. These techniques vary in effectiveness, with some (like freezing and chilling) being more energy-intensive, while others (like salting and smoking) rely on chemical and physical processes to inhibit microbial growth.

Modern preservation technologies, including microwave processing, pulsed electric field (PEF), irradiation, and high hydrostatic pressure (HHP), offer innovative, non-thermal alternatives that minimize nutrient loss while improving food safety and quality. These advanced methods provide efficient microbial inactivation, reduced processing times, and better retention of sensory and nutritional properties compared to conventional techniques. Despite these advancements, challenges remain, such as lipid oxidation, protein denaturation, and the need for cost-effective, scalable solutions. Future research should focus on optimizing hybrid preservation methods, reducing energy consumption, and enhancing the sustainability of seafood processing. By integrating traditional and modern techniques, the food industry can ensure safer, longer-lasting, and higher-quality seafood products for global consumers.

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Hybridization in Fruit Crops

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Hybridization

Hybridization refers to mating or crossing of two plants or lines of diverse genotypes to obtain a viable hybrid progeny. The seed as well as the progeny resulting from hybridization are known as 'hybrid' or F_1.

Hybridization in self-pollinated crops

By planned hybridization between carefully selected parents, the breeder can create populations with sufficient variability from which plants combining the desirable features of the parents can be selected. Theoretically, all the plants of pure-line or a clone are of one genotype (i.e. they have identical genetic constitution). Therefore, when different pure-lines or clones are crossed, heritable variability is created by recombination. Selection in the segregating generations of a hybrid will therefore be effective.

Objectives of hybridization

The purpose of hybridization is to combine in a single variety, the desirable characters of two or more lines, varieties or species. Occasionally, the recombination of genetic factors leads to the production of new and desirable characters not found in either of the parents. When two parents are crossed, the resultant F_1 is a homogeneous one but is heterozygous in nature, hence all plants look similar phenotypically. When they are selfed to produce F_2 the population is heterogeneous and heterozygous. Hence, phenotypically many variations could be seen in this generation. Further, in this generation, a cross may frequently give rise to progenies which are beyond the range of the parents for a particular quantitative character such as height of plant, earliness, fruit size, yield etc. This phenomenon is often referred as "transgressive segregation". For example, the progenies may be taller than the taller parent or earlier than the earlier maturing parent. Such transgresive segregation may enable the breeder to attain his objective quickly.

Types of hybridization

Inter-varietal hybridization

The parents involved in hybridization belong to the same species. There may be two strains, varieties or races of the same species. It is also known as intraspecific hybridization. The intra-varietal crosses may be simple or complex depending upon the number of parents involved.

Simple cross: In a simple cross, two parents are crossed to produce the F_1.

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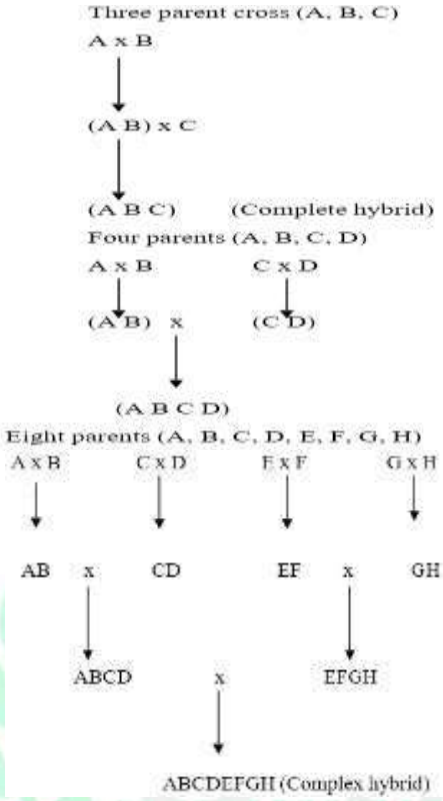
Complex cross: More than two parents are crossed to produce the hybrid.

Example



Hybridization techniques

There are seven steps involved in hybridization.

Choice of parents: It mainly depends upon the objective of breeding programme. In addition to other objectives, increased yield is always an objective for the breeder.

Evaluation of parents: If the performance of parents used for breeding is known, evaluation is not necessary. But if their performance is not known, it should be evaluated, particularly for the characters to which they are expected to contribute.

Emasculation: The removal of the stamens or anthers or the killing of pollen grains of a flower without disturbing the female reproductive organs is known as emasculation. The purpose of emasculation is to prevent self fertilization in the flowers of female parent.

Type of emasculation

- ✓ Hand emasculation
- ✓ Suction emasculation
- ✓ Hot water emasculation
- ✓ Alcohol treatment
- ✓ Cold treatment
- ✓ Genetic emasculation e.g.male sterility

Bagging: Immediately after emasculation, the flowers of the inflorescence are closed in suitable bags of appropriate size to prevent random cross pollination.

Tagging: Emasculated flowers are tagged just after bagging. The following information is recorded on the tags with a carbon pencil:

- ✓ Date of emasculation
- ✓ Date of pollination
- ✓ Name of the female and male parents. The name of female parent written first, and then the male parent

Pollination: Pollination refers to transferring the mature and fertile pollen from the male parent to the stigma of the female parent. This is done with the help of brush delicately with out disturbing the stigma and female flower. The pollinated flower is enclosed in a butter- paper bag or muslin cloth bag to avoid contamination from outside pollen and labeled. Few days after pollination, when the fruitset is conspicuous, the bag is removed. The seeds extracted from such crossed fruits are the F_0 seeds to raise F_1 or hybrid plants.

Selection procedures with hybridization

Two selection procedures are commonly followed after hybridization to isolate the desirable genotypes from the segregating progeny.

The pedigree method: This is widely followed by the plant breeders now, who maintain a detailed record of relationships between the selected plants and their progenies. It consists of the selection of individuals plants with the desired combination of characters in the F_2 generation and reselection of the progenies of each selected F_2 plant in succeeding generations until genetic purity is reached.

The bulk method: This method differs from the pedigree method in that the hybrids are grown in bulk till the F_5 or F_6 generation. Desirable individual plants are selected only in the F_5 or F_6 generation and these are then carried forward as families, which are evaluated in the same way as in the case of pedigree method.

Achievements

Fruit	Hybrids
Mango	Mallika, Amrapalli, Pusa Arunima, Arka Anmol, Ratna, Arka Puneet, Arka Aruna, Arka Neelkiran, Sindhu, PKM-1, PKM-2.
Guava	Arka Amulya, Safed Jam, Kohir Safed
Papaya	CO-3, CO-2
Sapota	CO-1, DHS-1, DHS-2, Hybrid 214, Hybrid-711
Banana	CO-1

Soil and Water Conservation Techniques

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Abstract

Soil and water conservation techniques aim to protect and improve the health of both soil and water resources, preventing erosion, runoff, and water pollution. These techniques can be broadly categorized into agronomic (related to crop management) and engineering measures (using physical structures). Key strategies include cover cropping, contour farming, mulching, and rainwater harvesting. Conservation of soil and water resources is important for sustainability of agriculture and environment. Soil and water resources are under immense pressure due to ever increasing population thereby ensuing growing demand for food, fibre and shelter. Soil and water resources are being deteriorated due to different anthropogenic and natural factors. Soil erosion is one of the several major deteriorative processes which results in deterioration of the soil. Soil erosion is removal of soil due to movement of water and/or air. Soil erosion may lead to the significant loss of soil productivity and thus may lead to the desertification under sever conditions. Water and wind are the major agencies which are responsible of soil erosion. Deforestation, over-grazing, intensive cultivation, mismanagement of cultivated soils and intensive urbanization are major factors triggering the soil erosion.

Introduction

Soil is the most fundamental resource to fulfil basic requirements of food, fibre and shelter of human race. The basis of all terrestrial life is soil although it is perceived as something of insignificant value and it is considered as dirt but humans cannot survive without soil. Soil and water conservation is a multifaceted approach that aims to protect and enhance both resources for sustainable agriculture and environmental well-being. It involves a range of practices and technologies to prevent soil erosion, improve water infiltration, and ensure efficient water use. The soil covering the Earth surface has taken millions of years to develop. The rate of soil formation is very slow (during every 100 to 400 years, only 1 cm soil is formed) and the enough soil depth is formed in 3000 to 12000 years to have a productive land. Thus, when soil, a non-renewable natural resource is ruined then it will be lost entirely (Pimentel *et al.*, 1995; Lal, 2001). Globally, out of 22% of the land suitable for sustaining agricultural productivity, around 5 to 7 M.ha are being lost annually due to land degradation, consequently, threatening food security of the world. Soil and water resources conservation and management is important for the welfare of the people.

In-Situ Moisture Conservation Techniques

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Functions

- ✓ To conserve in situ moisture and reduce soil loss
- ✓ Circular basin of one meter diameter for level lands depending upon infiltration and rainfall
- ✓ 'V' ditches of size 5m x 5m with trees planted centre and height according to the rainfall and slope of sloppy lands
- ✓ Saucer basins / semi-circular bunds with 2 m diameter to a height of 15-20 cm across the slope

Broad beds and furrows

Function	To control erosion and to conserve soil moisture in the soil during rainy days
General information	The broad bed and furrow system is laid within the field boundaries. The land levels taken and it is laid using either animal drawn or tractor drawn riders.
Salient features	Conserves soil moisture in dry land. Controls soil erosion. Acts as a drainage channel during heavy rainy days.

Contour bund

Function	To intercept the runoff flowing down the slope by an embankment
General information	It helps to control runoff velocity. The embankment may be closed or open, surplus arrangements are provided whenever necessary
Salient features	It can be adopted in light and medium textured soils. It can be laid upto 6% slopes. It helps to retain moisture in the field

Situations for various bunding options

Bunding options	Soil type	Rainfall (mm)	Slope (%)
Contour bund	Light soil	<600	>1.5
Graded bund	All soils	>600	1.5
Bench terraces	Deep soil	>1000	6.0
Graded boarder strip	Deep alfisol and related red soil	>800	>1.5

Soil Erosion: Soil erosion can be classified into two major types, i.e., accelerated and geological erosion. The normal process of weathering is geological erosion that usually happens as a part of natural soil-forming mechanisms at low rates in all soils. It is not affected by human activities as well as it happens at the period of long geological time. The processes influenced by the slow but constant geological erosion are the development and disintegration of rocks.

Stream bank erosion: In this type of erosion, breakdown of banks along streams, creeks, and rivers occurs due to the erosive power of runoff from uplands fields. Pedestals formation with fresh vertical cuts along streams is the reason of stream bank erosion. Exhaustive cultivation, grazing and traffic along streams, and presence of bare land accelerate stream bank erosion. This type of erosion can be reduced by planting grasses and trees, establishing engineering structures, mulching stream borders with rocks and woody materials, geo-textile fencing, and diverting runoff (Blanco and Lal 2008).

Soil Erosion Control

Causes: Soil erosion is primarily caused by water and wind, which can detach and transport soil particles, leading to the loss of fertile topsoil.

Impacts: Soil erosion reduces soil fertility, impairs crop yields, and can contribute to sedimentation of water bodies.

Prevention: Various methods are used to prevent soil erosion, including:

Contouring: Cultivating fields along the contour of the land to slow down water flow and reduce runoff.

Strip cropping: Planting different crops in strips to create a barrier against water and wind erosion.

Terracing: Creating level platforms on sloping land to reduce erosion and improve water infiltr-ation.

Windbreaks: Planting rows of trees or shrubs to protect fields from wind erosion.

Cover crops: Planting crops during the off-season to protect soil from erosion.

No-till farming: Leaving crop residues on the soil surface to protect it from erosion and improve water infiltration.

Water Conservation

Importance: Water is a vital resource, and its conservation is crucial for sustainable agriculture and water security.

Methods

Water harvesting: Collecting and storing rainwater for later use.

Efficient irrigation: Using irrigation techniques that minimize water waste, such as drip irrigation and micro-sprinklers.

Reducing water consumption: Implementing measures to reduce water usage in agriculture, industry, and households.

Improving water storage: Constructing dams, ponds, and other water storage structures.

Promoting water recharge: Implementing measures to improve groundwater recharge.

Soil and Water Conservation Practices

Agronomic practices: These involve managing crops and soils in ways that reduce erosion and improve water infiltration, such as contour ploughing, strip cropping, cover cropping, and no-till farming.

Engineering structures: These include structures like dams, ponds, terraces, and waterways, which are designed to control water flow, reduce erosion, and improve water storage.

Vegetative measures: Planting trees, shrubs, and other vegetation to protect soil and improve water infiltration.

Importance of Soil and Water Conservation:

Sustainable agriculture: Soil and water conservation practices are essential for maintaining soil fertility, ensuring crop yields, and promoting sustainable agriculture.

Environmental protection: These practices help to protect soil and water resources, prevent pollution, and maintain ecosystem health.

Climate change mitigation: Soil and water conservation can contribute to climate change mitigation by improving carbon sequestration in soils and reducing greenhouse gas emissions.

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Major Pests and Diseases of Capsicum

Bheemireddy Anuradha

Introduction

- ✓ Scientific name: *Capsicum annuum var. glabriusculum*
- ✓ Family: Solanaceae; Chromosome: 2n=24
- ✓ The name 'Capsicum' is derived from the Greek word 'kapto', meaning "to bite" or "to swallow".
- ✓ Mexico is believed to be the centre of origin of *C. annuum*, whereas *C. frutescens* and the other cultivated species (*C. baccatum var. pendulum, C. chinense and C. pubescens*) originated in South America.

- ✓ Up to 8% of the daily required intake of vitamin A, 180% of vitamin C, 2% of calcium, and 2% of iron can be found in one medium green capsicum. Depending on the season and type, the conventionally cultivated green capsicum typically produces 20-40 tons per hectare in 4-5 months. Green and colored capsicums can be grown in a greenhouse for seven to ten months, yielding 80 to 100 t per hectare.

Nutritive value of Capsicum

Rich in antioxidants: flavonoids, a type of antioxidant that helps shield the body from oxidative damage, and capsanthin, responsible for the rich red colour, and shield the skin against UVA and UVB damage.

Boost Immunity: a great source of Vitamin A and C, which strengthens the immune system.

Good for the eye: Lutein and zeaxanthin-carotenoids found in relatively high amounts in capsicum may enhance eye health.

Good for Heart: Capsicum is a great source of antioxidants, lycopene, Vitamin C, and Vitamin A, which are essential for heart health because they shield the heart from damage caused by free radicals.

Lower risk of cancer: Capsicum is a true superfood and contains a variety of cancer-fighting anti-oxidants, including apigenin, lupeol, luteolin, quercetin, and capsiate, and carotenoids such as beta-carotene, betacryptoxanthin, and lycopene.

Major Pests of Capsicum

Thrips (*Scirtothrips dorsalis*)

Symptoms: Thrips induce an upward curling of leaves, accompanied by brown scarring along the leaf veins, as they extract sap from the newly developed leaves at the top.

Thrips infected leaves and fruit

Additionally, they diminish leaf area and obstruct

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the plants' ability to absorb nutrients and water. A significant infestation results in the blackening and desiccation of leaves, malformed flower buds, irregular fruit production, stunted growth, and a marked decline in both fruit quality and yield.

Cultural Practices: Remove affected plant parts keep the plots clean

Chemicals: Spray Spinosad (Tracer) (1 ml L^{-1}) or Shakti 10 (1ml L^{-1}) or Ulala (0.5ml L^{-1}).

Capsicum Broad Mites (*Polyphagotarsonemus latus*)

Symptoms: Young larvae and adult insects consume leaves, buds, and fruits, extracting sap from various plant parts, which subsequently leads to the downward curling of leaves. The dimensions of leaves, fruits, and plants diminish, thereby impacting the market value of the produce. The prevalence of this pest infestation escalates with rising temperatures in conjunction with elevated humidity.

Mites infection on leaves and fruits of Capsicum

Cultural Practices: Remove pest-damaged plant parts, leaves, flowers and fruits.

Chemicals: Omite (1.5 ml L^{-1}) or Sarpanch (2 ml L^{-1}) or Shakti 10 (1 ml L^{-1}) or ecomite (1 ml L^{-1}) or Ulala (1 ml L^{-1}).

Aphids (*Myzus persicae*)

Symptoms: Nymphs and adult aphids extract sap from the veins of leaves and from younger foliage, leading to diminished plant growth and a reduction in yield. Their presence not only results in the curling of leaves but also facilitates the transmission of viral diseases within the crop.

Aphids infection

Cultural Practices: Roughing of weeds & use of reflective mulches

Chemicals: Chess (1 g L^{-1}) or Permit (2 g L^{-1}) or Sarpanch (2 ml L^{-1}) or Ulala (1 ml L^{-1}).

Resistant varieties: *Capsicum baccatum spp.*

Fruit borers (*Helicoverpa armigera, Spodoptera litura* Fab.)

Symptoms: Fruit borers exhibit significant activity during the night. The adult insects deposit numerous eggs on fruits, flowers, and leaves, while the nymphs that emerge from these eggs consume fruits and leaves, leading to substantial crop damage and a marked decline in produce quality. As the eggs are laid in clusters, the larvae tend to feed collectively on leaves in a single location, making them easily identifiable and susceptible to eradication.

Fruit borer damage in Capsicum fruits

Cultural Practices: Pick and destroy nymphs and

adult insects.

Chemicals: Thiodicarb (1 ml L^{-1}) or carbaryl (3 g L^{-1}) or indoxcarb (1 ml L^{-1}), Sarpanch (1 ml L^{-1}).

Diseases of Capsicum

Damping off (*Rhizoctonia solani, Pythium spp*.)

Symptoms: Infection occurs at the base of young seedlings, just above ground level, resulting in wilting and eventual death of the seedlings. Additionally, any damage inflicted on seedlings during the transplanting process can contribute to damping off or seedling wilt, along with new infections in the main field or infections that are transferred from the nursery.

Damping off in nursery

Cultural Practices: Use steam sterilized, light-weight & fast draining seed mix.

Chemicals: Captan (1 g L^{-1}) or metalaxyl MZ (2 g L^{-1}) or copper oxychloride (3 g L^{-1}).

Resistant varieties: Chocolate Bell, Big Bertha, Apple Hungarian

Powdery mildew (*Leveillula taurica*)

Symptoms: The condition first shows up as small yellow patches on the upper side of the leaf, with a powdery layer forming on the underside, creating a complete powdery covering on the lower leaf surface. As the disease progresses, it ultimately leads to the leaves drying out and dropping off. This ailment disrupts the growth of both leaves and fruits, resulting in a lower quality and quantity of the harvest.

Powdery mildew infected leaves and fruits of Capsicum

Cultural Practices: Locate plants in sunny areas, good air circulation, avoid excess fertilizer

Chemicals: Wettable Sulphur (2 g L^{-1}) or penconazole (0.5 ml L^{-1}) or flusilazole (0.5 ml L^{-1}).

Cercospora leaf spot (*Cercospora capsici*)

Symptoms: Cercospora initially manifests as a small yellow spot on the leaf surface, which subsequently develops into larger dark grey spots that proliferate across the entire leaf, ultimately causing the leaf to drop.

Cercospora leaf spot

Cultural Practices: Use disease free seed or treat seed with fungicides before planting

Chemicals: Chlorothalonil (2.5 g L^{-1}) or mancozeb (2.5 g L^{-1})

Resistant varieties: Bambino, Heritage, Intruder

Anthracnose (*Colletotrichum capsici*)

Symptoms: Fruit lesions represent the most prevalent symptom. The centers of these lesions may vary

in color from tan or orange to brown or black. Typically, concentric circles encircle the lesions. Ultimately, the entire fruit will decay. Anthracnose has the potential to induce a latent infection, wherein contaminated, immature fruits may remain asymptomatic until they reach full maturity.

Infected fruits of Capsicum with Anthracnose

Phytophthora (*Phytophthora capsici*)

Symptoms: This disease typically appears during the fruiting and flowering stages, marked by the development of small, oil-like spots on the leaves. These spots lead to the decay and darkening of the plants, which subsequently become weakened and can die within 2 to 3 days. Phytophthora disease is particularly severe in both open fields and net houses, with the potential to result in crop losses ranging from 40 to 80 percent.

Cultural Practices: Avoid sowing capsicum in severely affected net-houses.

Chemicals: Copper hydroxy chloride (3 g L^{-1}) or Ridomil (2 g L^{-1}) or azoxystrobin (0.5 ml L^{-1}).

Resistant varieties: Playmaker, Paladin, Aristotle, Turnpike, Captain.

Viral diseases of Capsicum

Symptoms: In viral diseases, the capsicum crop is primarily affected by leaf mottling virus and leaf curl virus, which are transmitted by aphids and thrips. This results in the curling of leaves both upwards and downwards, often accompanied by a yellow spot in the center of the leaf and occasionally on the fruit as well. Severe infestations can cause leaves to drop, hinder plant growth, and diminish both the quality and quantity of the fruits. Fruits that are affected by the virus become unmarketable.

Cultural Practices: Grow nursery beds under nylon cover (50 mesh), management of aphids, mites and thrips

Chemicals: Hydrogen peroxide at 6, 14, 18 Mm

Resistant varieties: PBC 462, Burning Bush, Camino Real

Phytoplasma

Symptoms: Phytoplasmas, a large group of plant-pathogenic, phloem-inhabiting bacteria were discovered by Japanese scientists in 1967. Symptoms of phytoplasma infection often include yellowing of leaves, changes in normal growth patterns ('witches-brooms'), and other abnormal growth, such as leaves in the place of flowers.

Phytoplasma infection in Capsicum

No chemicals are effective against phytoplasmas. Control these pathogens primarily through proper

sanitation, excluding and controlling insect vectors, and using only pathogen-free stock. Remove infected plants that are a source of pathogens, including certain weeds.

Nematode (*Meloidogyne incognita*)

Symptoms: Nematodes is common in capsicum, especially when cultivated in protected conditions 3-4 times continuously in the same field, where they feed on roots resulting in root dysfunction, reduced root volume, and efficiency in water and nutrient uptake. Initially yellowing of leaves can be observed, followed by reduction in leaf size, count and drastic reduction in size of fruits. When infected plant is uprooted and observed, small and big nodules filled with large number of nematodes nodules can be observed on roots depending on the level of infestation.

Cultural Practices: Crop rotation, apply bioagent like Trichoderma harzianum and Pseudomonas fluorescens along with farmyard manure at the time of field preparation, fumigation or solarization.

Chemicals: Apply Fluensulfone @ 1 g plant^{-1} or @ 20 kg acre^{-1} at the time of planting.

Resistant varieties: Charleston Belle, Carolina Wonder, Carolina Cayenne.

Underutilized and Underexploited Vegetable Crops: Pillars for Food Security, Nutrition and Climate Resilience

Sheetal Rana and Neha Jamwal

Introduction

The global agricultural landscape is dominated by a relatively small number of major staple crops, a dependency that presents inherent vulnerabilities to climate change, pest outbreaks and economic fluctuations. Despite the immense biodiversity of edible plants, a significant portion remains either underutilized or underexploited, largely neglected by mainstream agriculture and research. These "orphan crops" or "neglected and underutilized species" (NUS) hold immense potential to address some of the most pressing global challenges of our time: chronic malnutrition, food insecurity, climate vulnerability and declining agro-biodiversity. Underutilized and underexploited vegetable crops (UUCVs) refer to species that have historically been cultivated or gathered for food, but whose full potential is not being realized. This underutilization can manifest as limited cultivation area, minimal research investment, lack of integration into formal food systems or declining consumption. Often locally or regionally important, these crops are vital for the livelihoods and dietary diversity of specific communities, yet they remain marginalized globally. This article will delve into the definition and significance of UUCVs, explore their unique advantages, provide examples of prominent species and their benefits, analyze the challenges hindering their wider adoption, and outline strategic pathways for their promotion and mainstreaming into sustainable food systems.

Definitions

Underutilized Crops: These are the crop species that have been, or are currently cultivated on a limited scale within their traditional range. They are generally known and consumed locally but have not achieved their full potential regarding production, utilization or market development. Their genetic diversity might be eroding due to disuse, despite possessing desirable traits.

Underexploited Crops: This category typically refers to wild or semi-domesticated species that are gathered from natural habitats or cultivated on an extremely small, informal scale. Their potential is largely untapped, with minimal scientific study, and they may be unknown outside their very localized endemic regions and their genetic potential remains largely uncharacterized.

Why underutilized and underexploited crops?

- ✓ These plants thrive in marginal lands.
- ✓ They can endure both biotic and abiotic stress.
- ✓ They promote diversity.
- ✓ Maintains agro-ecosystem stability
- ✓ Achieves sustainable production with low-cost

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inputs

- ✓ Offers longer shelf life than commercial vegetables.

Benefits of Underutilized and underexploited vegetable crops (UUCVs)

- ✓ Nutritional superiority
- ✓ Climate resilience and adaptability
- ✓ Ecological benefits and biodiversity
- ✓ Socio-Economic benefits and livelihoods

A spectrum of underutilized vegetable crops

The diversity of UUCVs is vast, encompassing various plant parts consumed as vegetables across different agro-ecological zones. Here are examples illustrating their potential:

Underutilized leafy vegetables

Amaranth (*Amaranthus* spp.): Cultivated globally but often underutilized in formal systems. Rich in protein, iron, calcium and vitamins A and C. Highly adaptable to various climates and tolerant to heat and drought.

Moringa (*Moringa oleifera*): Often called the "miracle tree" or "drumstick tree." Its leaves are exceptionally rich in vitamins, minerals (especially iron and calcium), protein, and antioxidants. Highly drought-tolerant and fast-growing, making it ideal for arid and semi-arid regions.

Roselle (*Hibiscus sabdariffa*): The leaves are used as a sour vegetable and the calyces are used for drinks and jams. High in Vitamin C, anthocyanins, and other antioxidants. It is hardy and tolerant to heat and drought.

Ceylon Spinach (*Talinum triangulare*): A succulent leafy vegetable rich in vitamins A and C, iron, and calcium. It is tolerant to heat and humidity and can grow vigorously in various conditions, making it a reliable source of nutrition.

Underutilized root and tuber vegetables

African Yam Bean (*Sphenostylis stenocarpa*): A climbing legume producing both edible tubers and protein-rich seeds. Highly tolerant to drought and low soil fertility. Offers a valuable dual-purpose crop for food security.

Oca (*Oxalis tuberosa*): A South American Andean tuber. Known for its vibrant colors (red, yellow, purple) and tangy flavor. Rich in carbohydrates, Vitamin C and anthocyanins. Highly adaptable to high-altitude and cool climates.

Arrowroot (*Maranta arundinacea*): A tropical perennial producing starch-rich rhizomes. The starch is highly digestible, making it suitable for infants and those with digestive issues. It is a resilient crop suitable for tropical and subtropical regions.

Underutilized leguminous vegetables

Lablab Bean (*Lablab purpureus*): A versatile legume with edible pods, seeds, leaves, and flowers. Provides high-quality protein, fiber and micronutrients. Highly tolerant to drought and a wide range of soil conditions, and contributes to soil nitrogen fixation.

Jack Bean (*Canavalia ensiformis*): Cultivated for its young pods and seeds. Offers a good source of protein. Extremely hardy and tolerant to drought and poor soils, often used as a cover crop, but also has edible components that are underutilized.

Bambara Groundnut (*Vigna subterranea*): While often considered a pulse, its young pods can be consumed as vegetables. Highly adapted to dry conditions and marginal soils, fixing nitrogen and offering a highly nutritious complete food source.

Underutilized fruit vegetables

African Eggplant (*Solanum aethiopicum* / *S. macrocarpon*): A diverse group of eggplant relatives, varying widely in fruit shape, color, and bitterness. Rich in fiber, vitamins, and antioxidants. Important for food security in parts of Africa, showing good adaptability and disease resistance.

Snake Gourd (*Trichosanthes cucumerina*): A long, slender gourd vegetable used in Asian cuisines. Rich in vitamins and minerals, and known for its cooling properties. Adaptable to warm, humid climates.

Bitter Gourd (*Momordica charantia*): Though popular in some Asian and African cuisines, it remains underutilized in many other parts of the world. Known for its distinct bitter taste and significant medicinal properties, including anti-diabetic effects. Rich in vitamins, minerals, and bioactive compounds.

Challenges hindering mainstreaming

Strategies for promotion and mainstreaming: To mainstream UUCVs**,** focused R&D is essential for developing high-yield, stress-tolerant and nutritionally rich varieties. Strengthening value chains through market linkages, post-harvest infrastructure, and product diversification will boost profitability. Policy support should integrate UUCVs into food and agriculture agendas with targeted funding, seed systems and incentives. Awareness campaigns and farmer training are vital for adoption, while their climate resilience makes them key candidates for climate-smart agriculture.

Conclusion

Underutilized and underexploited vegetable crops represent a vast, untapped resource with profound implications for addressing current and future global challenges. Their inherent nutritional superiority, remarkable climate resilience, significant ecological benefits, and potential for socio-economic upliftment position them as indispensable components of sustainable and resilient food systems. Despite their immense promise, these crops face substantial hurdles related to research gaps, market access and policy neglect. However, through concerted efforts involving enhanced research and development, robust value chain creation, supportive policy frameworks, and targeted awareness campaigns, UUCVs can be effectively mainstreamed. Investing in these neglected gems is not merely an academic exercise; it is a strategic imperative for diversifying diets, enhancing food and nutrition security, building climate resilience and preserving

invaluable agro-biodiversity for future generations. Unlocking the full potential of underutilized vegetables requires a collective commitment to recognize their value and integrate them into the global agricultural agenda.

Nutritional Benefits of Fruits: A Comprehensive Analysis

Sarthak Sthitaprajnya

Abstract

Fruits are nature's bountiful gift, brimming with essential nutrients and vibrant flavors that make them a cornerstone of a healthy diet. They are rich in vitamins, minerals, antioxidants, and dietary fiber, all of which play pivotal roles in maintaining overall health and well-being. Key nutrients like vitamin C bolster the immune system and enhance skin health, while potassium supports heart function and regulates blood pressure. Fruits are also a fantastic source of dietary fiber, which aids digestion, promotes satiety, and helps prevent chronic diseases such as heart disease and type 2 diabetes. The natural sugars in fruits provide a healthy energy boost, making them a smart alternative to processed snacks. Moreover, fruits are loaded with antioxidants and phytochemicals, compounds that combat oxidative stress and inflammation, reducing the risk of chronic illnesses and supporting longevity. Their diverse range of flavors and textures can elevate any meal, whether enjoyed fresh, dried, or as part of a recipe. Eating a variety of fruits daily not only enhances nutritional intake but also adds color and excitement to your diet. Embracing seasonal and locally sourced fruits can offer even greater benefits, providing fresher, more nutrient-dense options. By making fruits a dietary staple, you can relish their health benefits and delightful tastes.

Introduction

The Importance of Nutrition: Nutrition plays a critical role in maintaining overall health and well-being. It provides the essential nutrients the body needs to function correctly, including energy for daily activities, building and repairing tissues, and supporting immune function Consuming a diverse range of foods, including fruits, vegetables, proteins, and whole grains, ensures that the body gets all the necessary vitamins, minerals, and macronutrients required for optimal health.

The Role of Fruits in a Balanced Diet: Fruits are vital components of a balanced diet due to their high nutrient density and low-calorie content. They are rich in vitamins, minerals, fibre, and various bioactive compounds that offer numerous health benefits. Fruits provide essential nutrients such as vitamin C, potassium, folate, and dietary fibre, which are crucial for maintaining health and preventing disease. Including a variety of fruits in the diet improve overall health and reduce disease risk.

Nutritional Composition of Fruits

Macronutrients: Carbohydrates, Proteins and Fats

Fruits primarily consist of carbohydrates, which provide a quick source of energy. The carbohydrate content in fruits includes natural sugars like fructose and glucose, which are easily digestible

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and provide an immediate energy boost. Additionally, fruits are rich in dietary fibre, which aids in digestion, helps regulate blood sugar levels, and promotes satiety. While fruits are generally low in protein and fat, they still contain small amounts of these macronutrients, which contribute to overall nutritional balance. The minimal fat content in fruits is usually healthy unsaturated fat, which is beneficial for heart health.

Micronutrients: Vitamins and Minerals

Fruits are abundant in essential vitamins and minerals that support various bodily functions. Some key micronutrients found in fruits include Vitamin C, Potassium, Folate (Vitamin B_9), Vitamin A.

Health Benefits of Consuming Fruits

Cardiovascular Health: Fruits contribute significantly to heart health by Lowering Blood Pressure, Reducing Cholesterol Levels, and Preventing Heart Disease.

Digestive Health: Dietary fibre in fruits supports healthy digestion by Promoting Regular Bowel Movements, Supporting Gut Health, Preventing Digestive Disorders.

Immune System Support: The vitamins and antioxidants in fruits enhance immune function by Boosting Immune Response, Protecting against Infections, Reducing Inflammation.

Fruits and Disease Prevention

Reducing the Risk of Chronic Diseases: Fruit consumption is linked to a reduced risk of chronic diseases due to their nutrient density and antioxidant content. Regular intake of fruits can lower the risk of Heart Disease, Stroke, Hypertension.

Fruits and Cancer Prevention: Certain fruits contain phytochemicals that may have cancer-preventive properties: Antioxidants, Fiber, Phyto-chemicals.

Managing Diabetes with Fruits: Fruits can be beneficial for individuals with diabetes by providing low glycaemic index options: Low Glycaemic Index Fruits, Fiber Content and Nutrient Density.

Seasonal and Local Fruits

Consuming seasonal fruits offers several nutritional and environmental benefits. The Higher Nutrient Density seasonal fruits are often fresher and retain more nutrients. They have Better Taste as Fruits picked at peak ripeness have superior flavour and texture. The Environmental Sustainability is more eating seasonal produce reduces the carbon footprint associated with long-distance transport-ation.

Integrating Fruits into Your Diet

Incorporating fruits into daily meals can be simple and enjoyable. In Breakfast we add fresh berries to yogurt, blend fruits into smoothies, or top

oatmeal with sliced bananas. In Lunch we can include fruit salads, add apple slices to sandwiches, or enjoy a piece of fruit as a side. In Dinner we can use fruits in savoury dishes, like pineapple in stir-fries or mango salsa with grilled fish. In Snacks we can keep fruits like apples, oranges, or grapes on hand for quick and healthy snacks.

Delicious and Nutritious Fruit Recipes

Here are a few easy-to-make recipes that highlight the versatility and deliciousness of fruits:

Berry Smoothie Bowl: Blend mixed berries, banana, and yogurt, and top with granola and fresh fruit.

Mango Salsa: Combine diced mango, red onion, cilantro, lime juice, and jalapeno for a fresh and tangy salsa.

Apple and Almond Butter Toast: Spread almond butter on whole-grain toast and top with thin apple slices and a drizzle of honey.

Citrus Salad: Mix segments of fresh citrus fruits, such as oranges and grapefruit, and drizzle with a light honey-lime dressing.

Berry Smoothie bowl

Mango Salsa

Apple & Almond Butter Toast

Citrus Salad

Conclusion

Summary of Nutritional Benefits: Fruits offer a multitude of nutritional benefits, including essential vitamins, minerals, fibre, and antioxidants. They support heart health, digestion, immune function, weight management, and chronic disease prevention. Regular fruit consumption is a key component of a healthy diet.

Encouraging Daily Fruit Consumption for Optimal Health: Incorporating a variety of fruits into daily meals is a simple and effective strategy for enhancing overall health. By enjoying the natural sweetness and diverse flavours of fruits, individuals can reap their numerous health benefits and contribute to a balanced, nutritious diet.

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The Benefits of Effective Agricultural Waste Management

Priya P. Satwadhar, Devshree D. Panchbhai and Bhavna Sharma

Introduction

Agriculture plays a central role in sustaining human life by providing food, fiber, and raw materials. However, it also generates a significant amount of waste ranging from crop residues and animal manure to agrochemical containers and processing by-products. This waste, if not properly managed, can pose serious threats to both the environment and public health. Moreover, poor waste management contributes to inefficiencies in agricultural production and adds to the economic burden of farmers. Effective agriculture waste management involves the collection, storage, treatment, and disposal or reuse of waste in a manner that minimizes negative environmental impacts and maximizes the economic value of agricultural by-products. It is a critical component of sustainable agriculture and is increasingly being recognized as essential by farmers, governments, and consumers alike.

Environmental Protection: Agricultural waste, if not handled correctly, can pollute water bodies, degrade soil, and contaminate air. Runoff from animal waste or excessive fertilizer use may lead to eutrophication of lakes and rivers, damaging aquatic ecosystems. Open burning of crop residues contributes to air pollution, which affects both local air quality and contributes to global climate change. By employing techniques like composting and controlled storage, farmers can mitigate many of these negative environmental effects. For example, composting organic waste such as manure and crop residues not only reduces the volume of waste but also prevents the leaching of nutrients into groundwater. Biodegradable waste can be transformed into compost, a valuable soil amendment that reduces dependency on synthetic fertilizers.

Benefits

Water Protection: Prevents leaching of harmful substances into water bodies.

Air Quality: Reduces emissions from open burning and uncontrolled decomposition.

Soil Preservation: Maintains soil health by minimizing chemical overloads and encouraging organic enrichment.

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Economic Advantages

Effective waste management can significantly reduce production costs and even become a source of income. Turning waste into biogas through anaerobic digestion provides farms with a clean and renewable energy source, which can be used for electricity generation, heating, or even fuel for vehicles. This can reduce the reliance on external energy sources and lower utility bills. Composting reduces the need for chemical fertilizers, which are often costly and may have long-term detrimental effects on soil health. In addition, processed waste products such as compost and organic fertilizers can be sold commercially, creating an additional revenue stream.

Benefits

Energy Production: Biogas generation reduces dependency on fossil fuels.

Fertilizer Savings: Compost can replace expensive chemical fertilizers.

- ✓ **New Revenue Streams:** Sale of compost, biogas, or biochar adds to farm income.
- ✓ **Operational Efficiency:** Reduces costs associated with waste transport and disposal.

Improved Soil Fertility and Crop Yield

Soil fertility is one of the most critical factors in agricultural productivity. The organic matter in agricultural waste contains essential nutrients like nitrogen, phosphorus, and potassium, which are vital for plant growth. When this waste is composted and returned to the soil, it improves soil texture, enhances microbial activity, and boosts its water-holding capacity. Long-term use of organic compost also helps build soil structure, making it more resistant to erosion and compaction. This improves crop root penetration and nutrient uptake, leading to higher yields and better crop quality. The use of organic inputs also aligns with the increasing consumer demand for sustainably grown and organic products.

Benefits

Nutrient Cycling: Reintroduces essential nutrients into the soil.

Enhanced Yield: Healthier soil produces more resilient and abundant crops.

Reduced Erosion: Organic matter improves soil cohesion and water retention.

Climate Change Mitigation

Agriculture contributes significantly to global greenhouse gas emissions, primarily through methane from livestock manure and nitrous oxide from fertilized fields. Improper disposal and decomposition of agricultural waste exacerbate these emissions. Adopting sustainable waste management methods can substantially reduce the sector's carbon footprint. For example, anaerobic digestion of manure not only prevents methane release but also captures it for energy use. Additionally, composting organic waste reduces the need for synthetic fertilizers which are energy-intensive to produce. Practices like biochar production, where biomass is converted into charcoal under low-oxygen conditions, also offer promising solutions. Biochar can sequester carbon for hundreds of years and enhance soil fertility at the same time.

Benefits

Lower Emissions: Proper manure management and composting reduce methane release.

Carbon Sequestration: Organic amendments and biochar improve soil carbon storage.

Resilient Systems: Sustainable practices help buffer the impacts of extreme weather.

Health and Hygiene

Health concerns arising from agricultural waste include the spread of waterborne diseases, respiratory issues due to smoke or dust, and contamination of food supplies. Manure, if not properly managed, can become a breeding ground for pathogens that affect both humans and animals. Proper waste management ensures that harmful pathogens are neutralized before waste is reused or disposed of. Composting, for example, raises the temperature of organic material to levels that kill most pathogens and weed seeds. Safe disposal of chemical containers and expired pesticides helps prevent accidental exposure and environmental contamination.

Benefits

Disease Prevention: Proper handling of waste reduces contamination.

Cleaner Environment: Decreases odor and pest infestations.

Safer Working Conditions: Reduces exposure to harmful substances and injuries.

Regulatory Compliance and Market Access

With growing awareness about environmental protection, governments have established strict regulations regarding agricultural waste management. Non-compliance can result in fines, operational shutdowns, or loss of licenses. Implementing sustainable practices not only ensures compliance but also enhances a farm's reputation. Certifications such as organic or sustainable agriculture can open up premium markets and improve consumer trust. Retailers and consumers increasingly prefer products from farms that demonstrate environmental responsibility.

Benefits

Legal Compliance: Avoids fines and shutdowns from environmental violations.

Certifications: Eco-labels and organic certifications enhance market appeal.

Consumer Trust: Builds brand value and loyalty through sustainable practices.

Conclusion: Agricultural waste should not be viewed merely as a problem but as an opportunity. When managed effectively, it can provide economic benefits, improve environmental outcomes, enhance public health, and contribute to climate resilience. Integrating waste management into the broader framework of farm operations is a key step toward sustainable agriculture. As the global population continues to grow, the demand for food and resources will intensify. Meeting this demand sustainably will require innovative solutions and responsible stewardship of natural resources. Effective agricultural waste management is a foundational practice that can help meet these challenges while supporting the livelihoods of farmers and protecting the planet.

Agriculture and Indian Economy: A Pillar of Inclusive Growth

Nandita Sinha and Priya Dhayal

Abstract

Agriculture and its allied sectors have always been the cornerstone for the Indian economy, providing livelihood, food security and contributing to national income. Despite a declining share in GDP due to industrialization and urbanization, agriculture remains crucial recording a 4.18 per cent annual growth rate as of 2025. This article explores evolving role of agriculture in inclusive economic growth through multiple dimensions: ensuring food security via diversified cropping and targeted government schemes, enhancing foreign exchange through exports, strengthening micro, small and medium enterprises (MSMEs) across agri-based value chains, utilizing byproducts for sustainability and circular economy goals, improving infrastructure to reduce post-harvest losses and promoting carbon farming to address climate change while generating income through carbon credits to realize agriculture's full potential as a pillar of long-term economic resilience and growth.

Introduction

Agriculture and its allied sector have long been the backbone of Indian economy, especially in the rural areas, playing a key role in generating national income and employment. As per the World economic outlook (2022), India has become the world's fourth largest economy. While the service sector contributes around 50 per cent of Gross domestic product (GDP), the agricultural sector provides employment to the majority of the work-force. According to the Press Information Bureau, Agriculture supports about 42.3 per cent of the population and contributes approximately 16 per cent to the GDP. Despite declining share in GDP due to industrialization, urbanization and monsoon dependence, agriculture remains vital recording a 4.18 per cent annual growth rate (PIB, 2025).

Given the relevance this article explores how agriculture continues to uplift the Indian economy through various dimensions.

Food Security: Food Security, as defined by the United Nations Committee on World Food Security, involves ensuring all people have access to sufficient, safe and nutritious food at all time. In India, food security promotes self-reliance, employ-ment, income generation and poverty reduction. As per the Global Hunger Index, 2024, India was ranked 105th out of 127 countries. Post the 1943 Bengal famine, the green revolution led to self-sufficiency but focused only on wheat and rice in selected regions. Therefore, the evergreen revolution consisting of diversified crops initiated at a single timeframe can shift the trend from achieving single objective goal towards more holistic and integrated

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resource management and farming systems for inclusive development.

Rice Transplanting Weeding Operation

Few government initiatives to enhance food security of the nation are:

- ✓ National food security mission (2007)
- ✓ Rashtriya Krishi Vikas Yojana (2007) later named as Rashtriya Krishi Vikas Yojana-Remunerative Approaches for Agriculture and Allied Sector Rejuvenation (RKVY- RAFT AAR)
- ✓ Pradhan Mantri Fasal Bima Yojana
- ✓ Integrated Schemes for Oilseeds, Pulses, Palm oil and Maize (ISOPOM)
- ✓ The National Food Security Act (2013) combat under- and mal-nourishments through Angan-wadi systems, mid-day meal schemes and subsidized grains through public distribution systems.
- ✓ Research activities also ensure food security in changing climate scenarios. From 2014-2024, out of 2900 released varieties of crops, 2661 varieties are climate resilient.

Increasing Foreign Exchange: Agricultural exports significantly contribute to foreign exchange and reduce import dependence. Agricultural exports as a percentage of India's agricultural GDP have increased from 9.4 per cent (2017-18) to 9.9 per cent (2018-19). While imports declined from 5.7 per cent to 4.9 per cent indicating an exportable surplus.

Key areas with export potential include:

- ✓ Cereals, which continue to dominate the export basket can be diversified
- ✓ Organic crops are potential products to fetch high value in the international market
- ✓ Dairy products India's position as the world's largest livestock population
- ✓ Livestock and fisheries products offer substantial export potential
- ✓ Horticultural products suffer huge post-harvest losses during transportation and storage can be declined by aligning towards value-added processing
- ✓ Production of high value crops such as Asafoetida in Leh and Ladakh region which were earlier completely imported
- ✓ Textile raw materials such as cotton, jute, *etc.*

Some of the government initiatives taken to increase foreign exchange values are:

- ✓ Operation Greens
- ✓ Market Access Initiative (MAI) facilitates global reach of agricultural products.
- ✓ Scheme for Agro-Marine Processing and Development of Agro-Processing Clusters (SAM PADA) aims to modernize agro-processing infrastructure
- ✓ National Horticulture Mission (NHM)
- ✓ E-NAM (National Agriculture Market)
- ✓ APEDA (Agricultural and Processed Food Products Export Development Authority)
- ✓ National Beekeeping and Honey Mission (NBH

M) to achieve the goal of 'sweet revolution'.

Emphasis on micro, small and medium enterprises (MSMEs): The MSME sector are key drivers of manufacturing, exports and employment. With 5.93 crore registered MSMEs employing more than 25 crore people, these enterprises generate a significant share of the country's economy. In 2023-24, MSME-related products accounted for 45.73 per cent of the nation's total exports, reinforcing their role in positioning the country as a global manufacturing hub. MSMEs in the agri sector are engaged in production, processing, marketing, distribution and servicing of agricultural products.

Few government initiatives taken to promote MSMEs in the agricultural sector are:

- ✓ Pradhan Mantri Formalisation of Micro Food Processing Enterprises Scheme
- ✓ Pradhan Mantri Kisan Samman Nidhi (PM-KISAN) provides income support
- ✓ Pradhan Mantri Matsya Sampada Yojana (PMMSY)
- ✓ Pradhan Mantri Kisan Urja Suraksha evam Utthan Mahabhiyan (PM-KUSUM)
- ✓ Pradhan Mantri Annadata Aay Sanrakshan Abhiyan (PM-AASHA) provides price assurance
- ✓ To encourage entrepreneurship among women, 'Skill Upgradation & Mahila Coir Yojana' is a training program aimed at skill development.
- ✓ Promotion of Contract farming for market-driven production

Utilization of Byproducts: Using Byproducts in agriculture promotes circular economy and sustainability. Under the flagship scheme "Swachh Bharat Mission" Indian Council of Agricultural Research (ICAR) has developed 140 value-added products, processes or processing equipment (organic manure, soilless media, biocompost technology, *etc*.) for converting agri-waste into wealth.

Other examples of byproduct utilization are:

- ✓ Steel slag and fly ash used as soil amendments
- ✓ Composting and biogas from agri-waste
- ✓ The initiative of government 'waste to wealth' mission such as Galvanizing Organic Bio-Agro Resources Dhan (GOBAR-Dhan) Scheme in 2018 for promoting Biogas and organic wastes recycling.

Improvement in infrastructure facilities: Infrastructure is an important element in every step of agriculture, starting from purchasing inputs to post-harvest management. As per NABARD Consultancy Services (NABCONS) 2022, India suffers food loss of about 17703.33 million dollars annually due to post-harvest losses of crops and allied produce. This loss accounts for approximately 22 per cent of the foodgrain output which is approximately 74 million tonnes of food wasted each year. The losses in horticulture (fruits, vegetables, plantations and spices) amounting to 49.9 million metric tonnes annually are primarily attributed to inadequate cold chain infrastructure. Such inefficiencies affect farmers and consumers while straining the country's economy and resources (water and energy inputs).

Government Initiatives:

- ✓ Agriculture Infrastructure Fund (2020)

- ✓ To promote scientific storage facilities in rural areas of the country Agricultural Marketing Infrastructure (AMI) which is a sub-scheme under the Integrated Scheme for Agricultural Marketing (ISAM).
- ✓ Mission for Integrated Development of Horticulture (MIDH)
- ✓ National Agriculture Market (e-NAM) Scheme
- ✓ Sub Mission on Agricultural Mechanization (SMAM)
- ✓ Mission Organic Value Chain Development for NE Region (MOVCDNER)

Carbon farming: It is a strategic approach of maximizing carbon sequestration and using agricultural practices to enhance the absorption of atmospheric CO_2 and retaining it in the plant biomass. India being a land of agriculture has significant economic potential in carbon farming approximately of 63 billion dollars from its 170 million hectares of arable land. Adoption of carbon credit system will bring additional income to the farmers and increase the GDP of the country.

Government initiatives:

- ✓ The Government notified Carbon Credit Trading Scheme (2023) and Voluntary Carbon Market (VCM) for the agricultural sector to encourage small and marginal farmers to get carbon credit benefits.

Conclusion

Agriculture continues to be the cornerstone of India's economy, not only as a source of food and livelihood but also as a driver of exports, enterprise and environmental resilience. While exporting, it is essential to account not just the value of the product but also the resources (water, *etc.*) used and the GHG emitted during production, to reflect the environmental costs and promote sustainable trade. Women, who contribute a significant share of the agricultural workforce, must be empowered through access to land, credit, training and technology. Similarly, the integration of digital agriculture tools like real-time weather advisories, precision farming, digital land records and e-markets can bring transparency, efficiency and empowerment to even the smallest farmers. In this regard, initiatives like the Pradhan Mantri Dhan Dhanya Yojana (2025-26) aim to strengthen low performing districts by increasing crop productivity, irrigation facilities and credit facilities by converging 36 schemes from 11 ministries to 1.7 crore farmers directly. The future of the Indian economy is deeply rooted in the prosperity of its farmers. A reimagined, inclusive and digitally empowered agricultural sector is not just an economic necessity but a national imperative.

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Safe, Smart and Sustainable: A Success Story of Maize Disease management with Eco-Friendly Techniques

Shakti Khajuria

Introduction

Maize, a major staple food crop in India, is highly vulnerable to various diseases under changing climatic conditions. In Gujarat, maize productivity is significantly constrained by leaf blights and spots like Maydis leaf blight, Turcicum leaf spot and Curvularia leaf spot. These diseases cause substantial yield losses if unmanaged. Acknowledging this challenge, ICAR-Krishi Vigyan Kendra, Panchmahal initiated frontline demonstrations during 2020-21. The aim was to showcase eco-friendly and sustainable disease management technologies, using seed treatment with *Trichoderma viride* and foliar application of neem leaf extract, thus reducing dependency on harmful chemical pesticides and improving farmer livelihoods.

Problem Analysis: Farmers in Panchmahal district were facing severe yield losses in *rabi* maize due to recurring outbreaks of leaf blight and leaf spot diseases. Traditional farmer practices involved the unscientific use of chemical pesticides, often ineffective against these pathogens. Additionally, poor awareness about biological control and inadequate adoption of integrated disease management (IDM) practices worsened the situation. With high disease incidence (25.50%) and low yields (26.25 q ha^{-1}), the profitability of maize farming was declining. There was an urgent need to introduce safe, cost-effective, and proven technologies that could reduce disease pressure and improve the crop's productivity and profitability sustainably.

Plan, Implementation and Support: To address this issue, ICAR-KVK Panchmahal implemented Frontline Demonstrations (FLDs) over during 2020-21 in four villages of Kalol taluka. A total of 20 innovative and receptive farmers were selected. The recommended technology, developed by AAU Anand, involved seed treatment with talc-based *Trichoderma viride* (2×10^8 cfu g^{-1}) @ 7 g kg^{-1} of seed, followed by four sprays of 10% neem leaf extract at 30, 40, 50, and 60 days after sowing. These demonstrations followed all standard agronomic practices and were monitored closely by KVK scientists. The control plots (non-FLD) used un-recommended chemical pesticides as per local farmer practices. Disease incidence, yield, cost of cultivation, and net returns were recorded. Extension activities like field visits, group discussions, and technical backstopping ensured farmer engagement. The participatory approach helped farmers observe the visible impact of biological disease management. Economic analysis and yield improvement were

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shared through on-field demonstrations, motivating other farmers to adopt these methods. This eco-friendly approach addressed the dual concerns of disease control and farmer profitability effectively.

Output: The frontline demonstration on maize disease management using seed treatment with *Trichoderma viride* and foliar application of 10% neem leaf extract showed significant improvement in crop health and productivity. The recommended practice recorded a lower disease incidence of 7.50% compared to 25.50% in the farmer's practice. This effective disease control contributed to a yield of 32.40 q ha^{-1}, which was 23.43% higher than the 26.25 q ha^{-1} obtained under traditional methods. Economically, the demonstration plots achieved gross returns of ₹51,840 ha^{-1} and net returns of ₹31,840 ha^{-1}, surpassing the farmer's practice, which yielded ₹42,000 ha^{-1} in gross and ₹22,900 ha^{-1} in net returns. Although the cost of cultivation under the recommended practice was slightly higher at ₹20,000 ha^{-1} (vs. ₹19,100 ha^{-1}), the benefit-cost ratio (BCR) was significantly better at 2.59, compared to 2.20 in farmers' fields.

Table 1: Performance of Recommended vs. Farmer Practices

Parameters	Recommended Practice	Farmer's Practice
Disease incidence (%)	25.50	7.50
Yield (q ha^{-1})	32.40	26.25
Yield increase (%)	23.43	-
Cost of Cultivation (₹ ha^{-1})	20,000	19,100
Gross Returns (₹ ha^{-1})	51,840	42,000
Net Returns (₹ ha^{-1})	31,840	22,900
Benefit-Cost Ratio (BCR)	2.59	2.20

These results confirm that the integrated use of bio-agents and botanicals is not only eco-friendly but also economically viable for managing maize diseases effectively.

Outcome: The adoption of the recommended practice led to a remarkable reduction in disease incidence and substantial yield improvement in maize. The success of the eco-friendly package using *Trichoderma viride* and neem extract encouraged participating farmers to adopt the technology regularly. Neighboring farmers were influenced to replicate the practice after seeing the on-field success. The integrated approach improved farmer confidence in biological disease management and reduced their dependence on chemical inputs.

Conclusion

The frontline demonstration proved that integrated disease management using *Trichoderma viride* seed treatment and 10% neem leaf extract sprays is a highly effective, eco-friendly, and profitable approach for controlling major maize diseases. The practice significantly reduced disease incidence, enhanced yield by 23.43%, and improved net returns and benefit-cost ratio compared to traditional methods. The technology is simple, cost-effective, and easily adoptable by farmers.

Encouraged by the success, farmers gained confidence in biological solutions and showed willingness to continue its use. This sustainable approach offers a practical solution for improving maize productivity while reducing chemical pesticide dependency.

Climate Resilient Rice Farming

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Introduction

In recent years, climate change has gained increased attention as a challenge for development. All the countries in the world are encountering the challenges of climate change through higher average temperatures, variability in precipitation and more frequent climatic extremes (Cradock-Henry *et al.*, 2020). Climate change is emerging as a major threat to the livelihood and food security of millions of people in many places of the world. It has a direct impact on the agricultural industry, particularly in developing nations where agriculture has a major share in the economy (Dissanayake *et al*., 2019), and it also has an indirect impact on economic growth, income distribution, household welfare, agricultural demand, etc. Furthermore, a significant percentage of rural residents in developing countries make their living from agriculture and related businesses, and climate change is resulting in significant declines in agricultural output. Due to their reliance on long-term, stable climate conditions, which are the basis for existing land-management and land-use decisions and practices, agriculture which includes crops and livestock is susceptible to climate change. Rice is the staple food for about half of the world population. Grown for more than 6000 years, it is economically, socially, and culturally important to a large number of people across the globe. More than 100 countries grow rice with the third highest worldwide production of 740 million tons (Mt) of rough rice, after sugarcane and maize. It accounts for 35-75% of the calories for more than 3 billion Asians. Globally, it provides 27% of dietary energy, 20% of dietary protein and 3% of dietary fat. Rice fields cover around 160 million hectares, the third largest cereal, and most important food of majority of global poor. Hence, exploring ways to increase rice production with less water is essential for increasing food security. Water-saving rice production practices like aerobic rice, alternate wetting and drying, direct seeded rice - DSR, raised beds, a system of rice intensification-SRI, a ground-cover rice production system - GCRPS, and rice-based conservation agriculture (Hobbs *et al.*, 2008), can reduce unproductive water outflows and increase crop water-use efficiency (WUE). However, these technologies can sometimes lead to a yield penalty with temperature rise and erratic precipitation patterns.

Need for Climate resilient of Agriculture

A World Bank research from 2020 estimates that 690 million people, or 8.9% of the world's population, are hungry, a number that has risen by

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about 60 million over the previous five years. The problem of food security would worsen since we will must increase food production by roughly 70% by 2050 in order to feed 9.8 billion people. The growing susceptibility of agriculture to climate change exacerbates this issue even further. Temperature increases, weather variability, agro-ecosystem shifts, invasive crops and pests, and an increase in the frequency of extreme weather events are some of the negative effects of climate change (McCarthy *et al*., 2011). Climate change has a negative effect on agricultural yields, the nutritional value of key grains, and the productivity of livestock at the farm level. As a result, significant adaptation expenditures are needed to preserve food production and maintain present yields. Climate resilient agriculture (CRA) is therefore desperately needed.

Climate change and rice production

The extent of the change demands more attention from water and agricultural managers, even though there is clear evidence of increased climate variability. In order to maintain agricultural output in the context of climate change, farmers will need to modify their plans to account for the new weather conditions that will recur for several more seasons.

Manipulation of crop establishment methods for climate resilient rice production

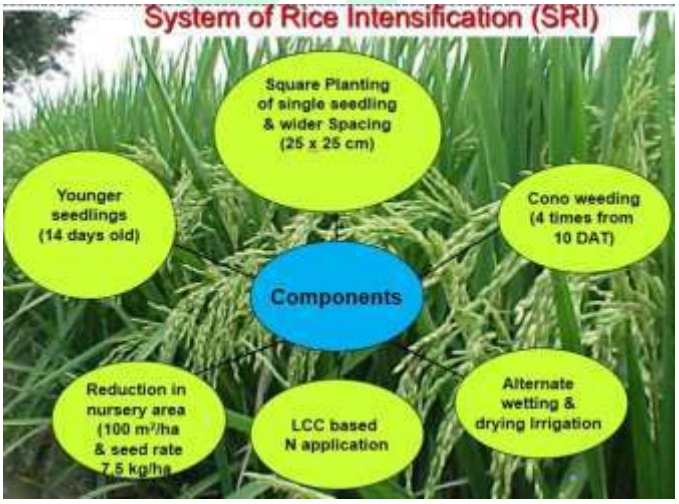
In the conventional system of rice production, that is transplanted rice (TPR), rice is traditionally transplanted using four to six week-old seedlings in well tilled puddled soils. Puddling is the practice of ploughing the field with standing water. Puddling creates anaerobic condition along with reduction in soil permeability. Standing water decays the weeds seeds thus, controlling weeds. The softening of soil helps in transplanting. The sedimentation of finer soil particles clog the pores resulting in reduction of deep percolation loss. Anaerobic condition increases the availability of plant nutrients viz., Fe, Zn, and P. About 30% of the total water is mainly consumed in puddling and seedling transplanting. Soil aggregates as well as capillary pores are broken due to puddling, clay particles are dispersed (crust formation on the surface of coarse-textured soil) and develop a hard pan that restricts root penetration for succeeding crops (Haque *et al*., 2016). It lowers hydraulic conductivity, raises bulk density, and degrades the physical characteristics of the soil. A major drawback of puddling, in addition to physical harm, is the loss of nitrogen (de-nitrification) in anaerobic conditions. Up to 30% of the irrigation water applied to the rice crop is used for puddling. Puddling causes the soil structure to be destroyed, increasing the energy needed to prepare the ground for subsequent harvests.

Direct seeded rice (DSR): Direct seeded rice (DSR) refers to the process of establishing the crop from seeds sown in the field rather than by transplanting seedlings from the nursery. This technique avoids puddling and does not need continuous submergence and thus reduces the overall water demand. It is therefore more pertinent to follow DSR technique for rice cultivation instead of the conventional TPR in

the changing climate scenario. Direct-seeding techniques have been shown to have a number of advantages over transplanting. In addition to greater financial benefits, the DSR method of installation is simpler, uses less water and labor, and is amenable to mechanization. Due to early flowering, DSR crops are said to have a shorter crop cycle and mature seven to ten days quicker. Greenhouse gas emissions in DSR are lower than in TPR. Since there are no growth delays brought on by transplant shock or injury, DSR usually establishes earlier than TPR. This helps the plant avoid the late-season drought by speeding up plant growth and development.

Zero/ minimum tillage transplanted rice: Regular tillage prevents water infiltration and root penetration by causing hardpan to form at the bottom of the plow layer. Repeated tillage not only degrades soil organic matter but also damages soil structure, which raises greenhouse gas emissions. These problems can be resolved by zero tillage or minimum tillage, which offers numerous benefits over traditional tillage. Because the soil is covered by the mulch from past crops, there is less soil erosion from wind and precipitation, less soil compaction, more resilient and productive soils, and less moisture evaporation in zero tillage.

Water-efficient rice production system: Technologies like aerobic rice, system of rice intensification and dry direct-seeded rice need less water to the tune of 20-60% than the conventional method of cultivation. Aerobic rice production technology is the method of growing rice under non-puddled and non-flooded conditions. The irrigation water is given at tensiometer reading in between 20 and 30 kPa, but shallow water @ 1-2 cm is maintained after panicle initiation. The system of rice intensification (SRI) is a package of practices which includes transplanting of 8-12 days old seedling (two-leaf stage), square transplanting of a single seedling using a marker, mechanical weeding, maintenance of moist soil under non-saturated conditions and application of organic manures for optimum biological activity. This technology saves 20-50% water, a requirement of 5 kg seed per hectare, provide higher productivity (35-40%), improve soil health and use efficiency and lower methane emission (50-60%).



Conclusion

Climate change is causing an increase in abiotic pressures such flood, drought, high temperatures, and salinity, which poses a major threat to rice production. A successful switch from traditional flooding to improved resilient rice production requires increased output. Resilient rice production systems that incorporate improved crop establishment techniques, enhanced water, weed and

nutrient management strategies, and the use of microbial resources have proven to be highly effective in water-stressed regions and for farmers with limited resources. The adoption of resilient rice production systems and utilization of microbial resources can improve overall productivity and yield potential of rice and help in mitigation of climate change.

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Insect Meal: Eco-friendly Approach for Sustainable Aquaculture

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Introduction

The rapid expansion of global aquaculture presents both opportunities and challenges for sustainable food production. Traditionally, aqua feeds have relied on fishmeal and fish oil derived from wild-caught fish, which exert pressure on marine ecosystems and contribute to environmental degradation. Insect meal has emerged as a promising alternative source of high-quality protein with potential to alleviate ecological burdens, diversify feed resources, and advance circular economy principles through waste valorisation.

Nutritional Profile of Insect Meal: Edible insects broadly serve as nutrient-dense raw materials, with protein content ranging typically from 30% to over 55% on a dry matter basis, depending on species, life stage, and rearing conditions (Shah *et al.,* 2022). Prominent insect candidates for aquafeed include Black Soldier Fly (BSF) larvae (*Hermetia illucens*), Mealworm larvae (*Tenebrio molitor*), Housefly larvae (*Musca domestica*), and Grasshopper meal. These insects provide not only balanced amino acid profiles rich in essential amino acids like lysine, methionine, and threonine but also valuable lipids including beneficial polyunsaturated fatty acids (PUFAs) such as omega-3 and omega-6 (Shah *et al.,* 2022). Reported protein contents in these insect meals approximate: BSF larvae 56.1%, Mealworm larvae 55.8%, Grasshopper meal 50.5%, and Housefly larvae 33.2% (Shah *et al.,* 2022). Minerals critical for fish health, such as calcium, phosphorus, zinc, and iron, are abundant in these insect biomasses, supporting optimal development and metabolism (Shah *et al.,* 2022). The bioavailability of nutrients from insect meals has been shown to be high, with digestibility coefficients exceeding 80% for essential amino acids in several fish species (Gasco *et al.,* 2024).

Environmental and Sustainability Advantages: From the perspective of resource efficiency and ecological footprint, insect farming represents a paradigm shift in feed ingredient production. Insects require significantly less land, water, and energy compared to conventional protein sources such as soybean or fishmeal (Nogales-Mérida *et al.,* 2019). They can be reared on organic side streams including food waste and agricultural byproducts, thereby reducing waste volumes and carbon emissions associated with disposal while producing high-value protein feedstocks (Shah *et al.,* 2022). Furthermore, shifting aquaculture feed formulations toward insect meal can mitigate overfishing pressures linked to

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fishmeal supply, contributing to marine biodiversity conservation and enhancing system resilience in the face of climate change (Islam *et al.,* 2024). Nevertheless, trade-offs exist; insect production currently entails elevated energy inputs for climate control in industrial rearing environments, highlighting a need for continued improvements to optimize sustainability (FAIRR Initiative, 2023).

Recent Advances and Commercialization Efforts: In recent years, the insect meal industry has experienced significant investment and technological innovation, driving progress from research to commercial scale. Several companies have developed pilot to full-scale insect farms producing larvae for use in aquafeed formulations, achieving feed inclusion levels of up to 25% without deleterious effects on fish growth or health (Islam *et al.,* 2024; Zorrilla and Dhaoi, 2023). Studies demonstrate that insect meal inclusion often enhances fish immune response and gut microbiota balance, traits critical for disease resistance under intensive farming conditions (Zorrilla and Dhaoi, 2023). However, production cost remains a barrier; insect meal prices significantly exceed traditional fishmeal, limiting widespread adoption despite clear nutritional advantages (FAIRR Initiative, 2023).

Impact on Fish Performance and Health: Several controlled feeding trials have addressed the suitability of insect meal as a substitute for fishmeal in various aquaculture species. Research confirms that partial replacement (up to 25%) of fishmeal with BSF, mealworm, or housefly larvae meals yields comparable or improved feed conversion ratios, growth rates, and protein digestibility in species including rainbow trout, European sea bass, and tilapia (Mastoraki *et al.,* 2020; Gasco *et al.,* 2024). Insect-derived chitin and antimicrobial peptides also contribute to modulating gut health and enhancing mucosal immunity, potentially reducing antibiotic use in aquaculture (Islam *et al.*, 2024). Notably, high inclusion rates above 30% may adversely affect digestibility due to chitin accumulation, underscoring the necessity for optimized processing techniques to reduce indigestible fractions (Gasco *et al.,* 2024).

Insect Meal Type	Protein Content (%)	Key Advantages	Challenges
Black Soldier Fly larvae	56.1	High protein, rich in lauric acid	Energy-intensive production
Mealworm larvae	55.8	Balanced amino acids	Higher production cost
Housefly larvae	33.2	Rapid reproduction	Lower protein content than BSF
Grasshopper meal	50.5	Natural diet component for fish	Variable nutrient composition

Black Soldier Fly Larva (BSFL) powder is rapidly gaining prominence as a sustainable protein source in the global protein market due to its high nutritional value and eco-friendly production process Typically containing around 40-45% protein by dry weight, BSFL powder offers a balanced amino acid profile comparable to traditional fishmeal and soybean protein, making it ideal for use in animal feeds, particularly aquaculture and poultry (Verified Market Reports, 2025; Shah *et al.*, 2024).

The global BSFL powder market was valued at approximately USD 400 million in 2024 and is projected to grow at a compound annual growth rate (CAGR) of 13.5%, reaching about USD 1.2 billion by 2033, driven largely by increasing demand for sustainable feed ingredients and government support for insect protein use (Verified Market Reports, 2025). In addition to its nutritional benefits, BSFL farming contributes to circular economy practices by converting organic waste into valuable protein, reducing environmental footprint compared to conventional livestock protein production. This combination of nutritional efficacy and sustainability positions BSFL powder as a critical player in the future protein market landscape.

Evaluating Black Soldier Fly (BSF) powder quality for aqua feed formulation involves several key steps focused on nutritional content, safety, and functional properties:

Proximate Analysis: Determine the basic compositional attributes including crude protein, crude fat, moisture, ash (minerals), and fiber content. High-quality BSF powder typically contains about 40-45% protein and 30-35% fat on a dry matter basis. Moisture content should be low (<10%) to ensure shelf stability and prevent microbial spoilage (Shah *et al.*, 2024).

Amino Acid Profile: Analyze the essential amino acids, especially lysine, methionine, threonine, and tryptophan, which are critical in nutrition for growth and progeny production. Balanced levels in line with nutrient requirements indicate good biological value of the protein (Gasco *et al.*, 2024).

Chitin Content: Assess chitin levels, the indigestible component from insect exoskeletons. While some chitin can benefit gut health, excessive amounts may reduce nutrient digestibility. Optimally processed BSF powder has moderate chitin content, improved by mechanical or enzymatic treatments (Islam *et al.*, 2024).

Microbial Safety and Contaminants Testing: Screen for microbial load, including pathogens like *Salmonella* and *E. coli*, and check for mycotoxins, heavy metals, and pesticide residues. Good manufacturing practices in insect rearing and processing ensure low contamination risk (FAO, 2023).

Functional Properties: Evaluate flowability, particle size, and water-holding capacity, as these influence mixing uniformity and feed pellet quality in feed manufacturing.

Digestibility and Feeding Trials: Conduct feeding trials or in vitro digestibility assays to confirm the bioavailability of nutrients and monitor performance indicators such as weight gain, feed conversion ratio, and health status post-inclusion of BSF powder.

Challenges in Scaling and Sustainability

Despite promising attributes, insect meal production faces hurdles impeding full-scale integration into aquafeed supply chains. Energy demands for climate control and specialized feed inputs elevate carbon footprints and production costs compared to projections (FAIRR Initiative, 2023). Supply remains constrained with global insect meal

availability estimated currently at only 12,000 tonnes annually, far below expectations. Regulatory frameworks regarding insect use in animal feeds continue evolving, with regional disparities impacting market access and consumer acceptance. Additionally, ensuring consistent nutrient composition, mitigating potential contaminants, and developing insect rearing systems adaptable to circular bio-economy principles are ongoing scientific and industrial challenges (Islam *et al.*, 2024).

Future Outlook and Innovation Directions

To actualize insect meal's potential for sustainable aquaculture, innovation is focusing on process optimization, genetic selection of insect strains, and utilization of low-value organic wastes as rearing substrates. Advances in biotechnology are exploring enzymatic treatments to reduce chitin content and improve digestibility. Expanding species-specific feeding trials and long-term health impact assessments will substantiate consumer confidence and regulatory approval. Integrating insect meal production within decentralized circular economies, including integration with aquaculture and agriculture systems, promises to enhance resource-use efficiency, reduce environmental footprints, and foster resilient food systems amid mounting global protein demands (Mboya, 2025).

Conclusion

Insect meal represents a nutritionally robust, environmentally advantageous alternative protein source that can transform aquaculture feed sustainability. The ecological benefits center on significant reductions in land, water, and marine resource use, coupled with waste valorization potential. Nutritionally, insect meals provide balanced amino acid profiles and bioactive compounds that support fish growth and immune health. Nevertheless, the commercial sector must overcome challenges related to production scale, cost, and regulatory landscapes to realize insect meal's broad adoption. Continued interdisciplinary research and innovation are imperative to optimize insect farming and processing, ensuring a viable, eco-friendly protein supply line that contributes meaningfully to sustainable aquaculture futures.

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Impact of Climate Change and Global Warming on Crop Pollinators

Nagendra Kumar, Mukesh Kumar Singh and A. Sivaraman

Introduction

Insects and other animal pollinators play a vital role in the production of crops for food, fiber, edible oils, pharmaceuticals and other goods. More than 1,300 different plant species are grown around the world for food, beverages, pharmaceuticals, condiments, spices and even textiles. Animals pollinate over three-fourths of these. Pollinators are directly responsible for more than one out of every three bites of food or liquids we consume. Pollinators such as bees, birds and bats affect more than one-third (35%) of global crop productivity. Pollinators mediate reproduction for a large share of the world's flowering crops and wild plants; many staple and high-value crops show yield or quality improvements only when insect-mediated pollination occurs. Pollination depends on a complex set of interactions among plant phenology, pollinator life histories, and local microclimates. Climate warming and associated change, long-term increases in mean temperature, altered precipitation regimes, more frequent heatwaves, and shifting seasonality, alter each component of this interaction network. The outcome is not uniform: some taxa and regions gain suitability while many specialist and cold-adapted species lose habitat and reproductive success (Rahimi *et al.*, 2024). Recent assessments reveal multi-faceted, often non-linear effects that cascade into crop yield risk.

Mechanisms by which warming alters pollination

Range shifts and changing climatic suitability: As for many ectotherms, bee species' climatic envelopes are shifting poleward and upward in elevation. Models indicate expansions in some generalists but contractions in many specialists, producing net losses of pollinator diversity in critical crop systems (Rahimi *et al.*, 2024). These reshufflings can sever historical plant-pollinator pairings, particularly where sessile plants remain while pollinators relocate.

Phenological mismatch (flowering vs pollinator activity): Temperature and precipitation shifts alter the timing of flowering and insect emergence. When plants flower earlier or later than the peak activity of their pollinators, pollination success declines even if absolute pollinator abundance does not. Empirical records show frequent advancement of flowering dates but inconsistent insect emergence shifts, leading to local mismatches that reduce fruit set.

Direct thermal stress and nest microclimate fail-

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ure: Bumblebee colonies exhibit sharp reproductive decline when nest temperatures exceed ~36°C. Field and laboratory studies confirm larval mortality, reduced worker vigor, and weaker queens during heat events. These demographic shocks are independent of gradual range shifts and act as acute population bottlenecks (Kerr *et al.*, 2020).

Interacting stressors: pesticides, pathogens and nutritional limitation: Warming can amplify pesticide toxicity, alter pathogen dynamics, and reduce floral nutritional quality. Experiments show synergistic impacts between high temperatures and pesticide exposure on survival and fecundity (Nebauer *et al.*, 2024). Likewise, changes in plant communities under climate stress reduce diverse pollen and nectar resources, limiting pollinator immune competence.

Empirical trends and quantified impacts

Population losses and extinction risk: Syntheses suggest that more than 20% of assessed pollinator species face elevated extinction risk under current and projected climate pressures. Invertebrate groups such as wild bees are especially vulnerable in regions experiencing rapid warming and agricultural intensification.

Managed honeybee losses and crop dependencies: Surveys from North America and Europe document overwinter losses often exceeding 40-50% of managed honeybee colonies, particularly following hot, dry summers. Crops highly dependent on managed hives: *e.g.*, almonds and berries, face rising costs and reduced pollination reliability (Seitz *et al.*, 2021).

Case studies: bumblebees and heat-induced colony failure: Long-term monitoring shows that bumblebee distributions are retracting southwards, consistent with thermal intolerance (Kerr *et al.*, 2020). Experimental work reveals that nests subjected to repeated heatwaves suffer reduced queen productivity and lower colony survival.

Indian Crop Pollinators and Climate Change

***Apis cerana indica* (Indian honeybee):** This native bee is widely managed in rural and peri-urban beekeeping across India. Heatwaves in central and southern India have been linked to reduced foraging hours and decreased honey yields in *A. cerana* colonies (Kumar *et al.*, 2022).

***Apis dorsata* (rock bee):** Found nesting on tall trees and cliffs in forest landscapes of central India and the Western Ghats. Increasing forest fragmentation and rising night temperatures reduce the stability of their open-air nests. In Madhya Pradesh, rock bee populations have shown shifts in nesting sites toward less disturbed habitats (Bhattacharya *et al.*, 2021).

Forest-Dependent Stingless Bees

***Tetragonula iridipennis* (Indian stingless bee):** Common in Kerala, Karnataka, and Tamil Nadu. Stingless bees provide critical pollination for medicinal plants and fruit crops in tropical forests. Higher rainfall variability and land-use change have reduced the abundance of floral resources, forcing these bees to shift foraging to cultivated areas (Nair and Rajasree, 2020).

Mountain Bumblebees of the Himalayas

***Bombus haemorrhoidalis* and *Bombus breviceps*:** These bumblebee species pollinate high-altitude crops such as buckwheat, apples, and large cardamom in the Eastern Himalayas (Sikkim, Arunachal Pradesh).

Recent studies show upward shifts in their elevation range due to warming, reducing overlap with traditional crop zones (Saini *et al.,* 2023). Farmers in Himachal Pradesh report reduced pollination in apple orchards at mid-elevations, coinciding with bumblebee declines, while higher-altitude farms gain some pollination services from newly arriving bee populations (Verma and Partap, 2021).

A concise synthesis table

Pathway	Observable effect on pollinators
Climatic envelope shift	Local extirpation of specialists; range shifts of generalists
Phenological mismatch	Reduced fruit set, inefficient pollination
Extreme heat / Heatwaves	Larval mortality, reduced queen fitness
Interaction with pesticides	Synergistic decline in reproduction
Managed bee colony losses	Reduced pollination supply

Consequences for crop production and food security: Pollinator declines do not translate linearly into crop losses, since some crops rely less heavily on animal pollination and substitutes exist. Yet economic modelling shows that reduced pollinator diversity elevates risks to yields and quality for fruits, vegetables, nuts and legumes. Global simulations suggest pollinator losses would reduce fruit and vegetable availability, raising prices and increasing nutritional risks for vulnerable populations (Gallai *et al.,* 2023).

Adaptation and mitigation: evidence-based options

Landscape and habitat strategies: Restoring floral diversity and nesting habitats buffers against thermal and phenological risks. Evidence shows that wildflower strips, hedgerows and habitat corridors support a more diverse pollinator assemblage with higher climatic tolerance.

Managing thermal stress and microclimates: Interventions such as hive shading, better ventilation designs, and relocation away from heat-prone sites reduce mortality during heatwaves. Experimental studies confirm that such measures improve brood survival in bumblebees and managed honeybees.

Integrated chemical management and disease control: Because pesticide toxicity increases at high temperatures, reducing reliance on broad-spectrum chemicals and adopting integrated pest management lowers combined risk. Disease surveillance and resistant stock breeding are additional adaptive measures (Nebauer *et al.,* 2024).

Policy and monitoring improvements: Long-term pollinator monitoring integrated with climate and land-use datasets remains limited. Expanding coordinated surveys and incentivizing on-farm habitat restoration through policy can reduce systemic risk.

Research rationale and priorities

Trait-based vulnerability mapping: Linking physi-ological tolerances with projected climates (Rahimi *et al.,* 2024).

Interaction experiments: Quantifying realistic

multi-stress impacts on colony dynamics (Nebauer *et al.*, 2024).

Crop-specific risk assessments: Connecting pollinator decline with yield and price projections (Gallai *et al.*, 2023).

Socio-ecological interventions: Testing cost-effectiveness of habitat and hive-design strategies.

Conclusion

Climate change is altering pollinator ecology through shrinking climatic envelopes, mismatched phenologies, and direct thermal stress. These drivers interact with pesticides, pathogens and land degradation to amplify threats. Evidence from global modelling (Rahimi *et al.*, 2024), field studies of bumblebee nest overheating, and surveys of honeybee colony losses indicates that pollination services are becoming less predictable and more expensive. Safeguarding crop pollinators requires integrated mitigation (emissions reduction) and adaptation (habitat restoration, improved hive management, pesticide reform, long-term monitoring). Treating pollinator resilience as a core element of agricultural climate adaptation will be decisive for maintaining food security in a warming world.

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Aquatic Pollutants: Threats to Aquaculture and Biodiversity

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Introduction

The word pollution can be simply defined as the introduction of a contaminant into a naturally healthy environment that causes an undesirable change that threatens the survival of existing plants and animals. Pollution has been a major concern in our society for several decades now as it brings about the deterioration in health and also gradually wears off the beauty and aesthetic value of our ecosystem. Developing countries are experiencing unprecedented and indiscriminate growth in human population, and as such, there is a further development in urban areas and constant establishment of more industries to meet up with the demand of the masses. The majority of these industries fail to carry out an environmental impact assessment (EIA), thereby having little or no regard for the eventual effect of their waste product on the community. Environmental pollution is one of the vital issues facing humanity today. It can be defined as "the alteration in the normalcy of the environment such that environmental processes are affected advers-ely." Construction, transportation and manufacturing as a means of development in the society, produce a large number of waste products, thereby polluting water and also cause depletion in natural resources. Pollution to the atmosphere causes global warming and brings about acid rains and also cause depletion in natural resources. Pollution to the atmosphere causes global warming and brings about acid rains. Human activities whether directly or indirectly cause a ripple effect of damage to the environment. Human activities whether directly or indirectly cause a ripple effect of damage to the environment (Ogamba *et al.*, 2021). Numerous human activities result in the release of different contaminants into aquatic ecosystems, endangering the health of living things and lowering environmental quality by making water bodies unsuitable. Anthropogenic contamination, industrial waste, and leakage of solid or chemical pollutants are all common in aquatic ecosystems (Bhat *et al*., 2017). These pollutants lead to "aquatic pollution problems" and may include "heavy metals, detergents, microfibers, plastic or non-plastic origin," among other things. Aquatic environs are addressee for plenty of pollutants and their outrageous toxic actions. "Aquatic ecosystems, particularly the freshwater ecosystems, are exposed to supplementary contamination than other environs, as water is used in various indus trial practices as well as release of discharges commencing from industry" and urban growths (Demirak *et al*., 2006).

Aquatic Ecosystems: Aquatic ecosystems are water-based environments in which biotic compone-

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Table 1: Sources and route of pollutant discharge into aquatic environment

Contamination	Source	Route
Infectious disease agents	Domestic sewage, human and animal wastes	Washing, swimming or working in paddy rice fields and on irrigated land
Plant nutrients such as nitrate, phosphate and others	Fertilized farm lands, ashes and detergent	Run-off from fertilized farmlands
Oxygen- demanding wastes (organic pollutants)	Domestic sewage, human and animal wastes (such as wastes from canneries and wood pulp mills)	Thrown, dumped or released into streams and rivers or into gutters, drains from where they may get washed by run-off into water bodies
Pesticides (insecticides and herbicides)	Organic and inorganic chemicals	Run-off from pesticides associated with farmlands
Industrial effluents which include DDT, dyes, mercury, cadmium	Textile factories, distilleries pulp and paper mills, fertilized plants, chemical and allied industry, food, beverages and tobacco industries, soap, detergents and confectionery industries	Human discharges
Petroleum products	Drill cuttings, drilling mud (fluids used to stimulate the production processes), accidental discharges of crude petroleum, refinery effluents which include oil and grease, phenol, cyanide, sulphide, suspended solids	Petroleum, exploration, exploitation, refining, transportation, storage, marketing, use and ruptured oil pipelines

nts interact with abiotic components of the aquatic ecosystem. "Aquatic ecosystems" are usually divided into two types: the "marine ecosystem" and the "freshwater ecosystem" (Barange *et al*., 2010). Marine ecosystem is the largest water ecosystem which covers over 70% of the Earth's surface. The marine ecosystem is subdivided into "oceans," "estuaries," "coral reefs," and "coastal ecosystems." Freshwater eco systems cover less than 1% of the Earth's surface. The various kinds of freshwater ecosystems are lotic ecosystem, lentic ecosystem, and wetland ecosystem.

Agrochemicals: The ever-increasing "demand for food has led to the land clearance and the expan sion of agriculture" which have "contributed to the higher pollution loads in the water". Increase in the population growth has increased the food demand, which has resulted in the increase in the quantity of agrochemicals used to increase the production. The "unsustain able use of agrochemicals" (fertilizers, pesticides, herbicides and plant hormones) to rise the production has resulted in greater pollution masses in the environment, including rivers, lakes,aquifers, and coastal waters.

Nutrients: When "fertilizers are applied at a higher rate than they are fixed by the soil, or taken up by the crops or when they are taken off through surface runoff from the soil sur face leads to water pollution. Excess nitrogenous fertilizers and phosphate fertilizers can leach into groundwater or reach into surface water bodies through surface runoff. The "high-nutrient concentration together with other substances results in the nutrient enrichment eutrophication of lakes, reservoirs, ponds, and

coastal waters, which leads to excessive growth of aquatic plants-algae blooms that destroy other aquatic plants and animals.

Sewage: Sewage makes up the largest amount of waste discharged into the aquatic ecosystems. Industrial wastes, municipal wastes, and domestic wastes, including wastes from baths, washing machines, kitchens, and feces, are all found in sewage. The best sinks for the discharge of these wastes are fresh water sources (Das and Acharya, 2003). It is estimated that 58% of the wastewater from urban areas and 81% of industrial wastes are discharged directly into water bodies with no or inadequate treatment results in contamination of ~73% of the water bodies. Sewage is comprised of several microorganisms, heavy metals, nutrients, radionuclides, pharmaceutical, and personal care products." Sewage is primarily organic in nature; owing to the organic load of sewage, the "oxygen concentration in the receiving waters is reduced, thus sewage is said to have a high BOD." The "effect of maltreated sewage on surface water is largely determined by the oxygen balance of the aquatic ecosystem, and its presence is essential in maintaining bio logical life within the system.

Heavy Metals: Heavy metals enter the aquatic ecosystem from both natural and anthropogenic sources." Entry may be as a result of "direct discharges into both fresh and marine ecosystems or through indirect routes such as atmospheric deposition and surface run-off. Important "natural sources are volcanic activity and weathering of rocks. Heavy metals are natural constituents of rocks and soils and enter the environment as a consequence of weathering and erosion. Heavy metals in "aquatic system can be naturally produced by the slow leaching from soil/rock to water, which are usually at low levels, causing no serious lethal effects on human health.

Impact of aquatic pollutant on Biodiversity and Aquaculture system

Destruction of Mangrove Forests: Aquaculture farms" are constructed in "mangrove forests". Mangrove forests are important ecosystems as they act as nurseries for many aquatic species as well as nesting areas for birds, reptiles, crustaceans and other taxonomic groups. The cover of mangrove forest has decreased worldwide from 19.8 million hectares in 1980 to less than 15 millions hectares in 2000. The annual deforestation rate was 1.7% from 1980 to 1990 and 1% from 1990 to 2000 (FAO, 2007), and the problem of deforestation still continue today. Aquaculture has been responsible for the deforest-ation of millions of hectares of mangrove forest in Thailand, Indonesia, Ecuador, Madagascar and other countries.

Eutrophication of Receiving Waters: One of the main causes of eutrophication or organic loading in the receiving waters may be aquaculture. It is mostly

made from "uneaten feed," particularly from over-feeding and lixiviation of aquaculture feedstuffs. Only 20-50% of the total nitrogen provided to the cultivated organisms is maintained as biomass by the farmed organisms, with the remainder being incorporated into the water column or sediment, as is well known. When fresh water quality is deteriorated by organic contaminants, dissolved oxygen (DO) in the water is consumed. As a result, DO falls, fish and other aquatic life are exposed to harsh conditions, or they are killed by hypoxia in water bodies.

Impact on Water quality: The temperature of water increased during the thermal pollution where water is used for cooling power stations and also waste heat from industries. Due to the discharged of heavy sewage pollution and effluents containing high organic matter into any water body reduced greater amount of dissolve oxygen level. DO are also broken down by the physiological activity of micro-organisms by using dissolved O_2.

Impact on aquatic biota: Water-dwelling aquatic plants known as macrophytes are divided into three categories: submerged, floating, and emergent. Because they react swiftly to the pace and variety of numerous environmental factors, including as water flow, alkalinity, substrate, shading, and nutrient concentrations, macrophytes serve as bioindicators. Because it reduces the amount of light that can penetrate the water column, total suspended sediment has a negative effect on algae and aquatic macrophytes, which in turn reduces the frequency of photosynthesis. Fast-flowing rates frequently carry a large amount of suspended materials and also remove algae and aquatic macrophytes off bed surfaces, damaging their photosynthetic systems in the process. A high quantity of suspended water pollutants can interrupt the normal behaviour of fish populaces. Various fish species rely on sight to catch their prey quickly e.g. perch, brown trout, etc. are most susceptible to the high quantity of suspended solids and shows very strong avoidance behaviour. In some cases where the fish species survive in turbid water habitat, suspended solids can clog/harm gills aperture and reduced the resistance towards various disease and parasites.

Mitigation Strategies and Recommendations

To reduce aquatic pollution, a number of strategies are employed, from preventing pollutants from entering waterways to cleaning them up after they have already been released. Membrane filters and biofiltration are two technologies that should be employed to ameliorate the effluent from municipal and industrial sources. Sustainable farming practices, such as buffer zones near water sources, organic farming, and limited fertilizer use, can lower non-point source runoff. Promoting circular economy models and encouraging the reduction, reuse, and recycling of materials especially plastics-are also essential for the long-term protection of aquatic environments. Aquatic ecosystems should be cleansed of metals and pesticides through the use of bioremediation processes. Implementing real-time monitoring systems can significantly reduce the amount of pollutants released into aquatic bodies.

Effective wastewater discharge management, including regulation and monitoring, is necessary to protect aquatic habitats. Regulatory frameworks should establish stringent water quality standards, and frequent reporting and monitoring should be employed to guarantee adherence. Furthermore, community involvement in public awareness campaigns and monitoring programs can promote ecologically friendly wastewater treatment methods and increase the effectiveness of legislative activities.

Conclusion

Different types of impurities and toxins enter into the aquatic ecosystem and impact the water quality and disturb the life cycle of aquatic organisms. Some pollutants are very active to damage the aquatic organisms both morphologically and metabolically. Nevertheless, there is only inadequate evidence that water impurities and pollutants are truly accountable for the expansion of disease in aquatic animals. The revelation of aquatic animals to pollutants for the long term caused the ceaseless risk of health. At the scientific, policy, and community levels, swift and cooperative action is required to minimize harm and protect aquatic species. The restoration of ecological balance and the resilience of aquatic habitats can be achieved by placing a strong emphasis on pollution control, ecosystem-based management, and sustainable aquaculture methods.

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Microbiology and Biochemistry of Pesticide Degradation

Narayan Dattatraya Totewad

Introduction

Currently, there are 5000 mega hectares (38% of the Earth's surface) of land on Earth that have been recorded as being used for agricultural development. This surface can be divided into three parts, where one part represents crops, and the remaining two are prairies and pastures. To keep crops suitable for human consumption, free of pests, and maximize their production, it is necessary to apply pesticides; according to Clark and Tilman (2017), by 2030, the world population is expected to reach 8.5 billion people, which in turn will increase the use of pesticides. The World Health Organization (WHO) classifies pesticides based on their level of hazard as determined by the lethal dose (LD_{50}). A pesticide is any material that has the ability to destroy, diminish, prevent, repel, control, attract, or even kill a pest or non-target organism in rats. The individual handling the product is impacted by exposure to the chemical, whether it is from a single exposure or several exposures over a brief period of time. The ecosystem and non-target animals are negatively impacted by pesticides, so efforts are always being made to develop ways to lessen their effects. Microorganisms can adapt and grow in a variety of situations thanks to their significant metabolic diversity. Microorganisms are a good tool for soil and water remediation because of this and other characteristics. Furthermore, using them is typically less expensive than using physical and chemical approaches (Carles *et al*., 2021). The great variety of microorganisms that have the capacity to degrade pesticides include fungi, bacteria, actinomycetes, and algae; these organisms can use xenobiotic compounds as a source of nutrients. These microorganisms can use xenobiotic compounds as a source of nutrients through the use of enzymes. Nowadays the governments and higher authorities of different countries are taking firm steps towards these critical issues. For this reason, it is necessary to generate strategies for the bioremediation of polluted sites and waste treatment. From an economical and environmental point of view, the biological treatment is an important technology. Recently, the use of native or genetically modified organism to degrade or remove pesticides has emerged as a powerful technology for in situ remediation. There are many investigation reports of different organisms like bacteria, algae, yeasts, fungus and plants, characterized in relation to their genome and the enzymes that they produce, that can be utilized for waste treatment or bioremediation of soil and water.

Biodegradation of Pesticides

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Certain pesticides are persistent contaminants in the environment because of their high resistance to degradation. Furthermore, the most of them might be regarded as health issues. New techniques, such biodegradation, are required to remove these compounds from the environment because of their chemical stability. As Matsumura *et al*. (1982) correctly point out, using microorganisms that can biodegrade these polluting substances found in soil and water is one environmentally benign approach. Microorganisms have a strong capacity to adapt to the constant changes in the environment they inhabit, for example, mutation or induction. Microorganisms will use different types of metabolisms to metabolize these xenobiotic compounds, which they can later use as a source of carbon, nitrogen, phosphorus, energy, *etc.* Microbial metabolism of the pesticides ends in one of two scenarios: the complete biodegradation of the molecules or the mineralization of it; in this case, most of the by-products are suitable for their re-entry into the environment. It should be emphasized that pesticide biodegradation is less expensive than traditional methods, which makes it financially viable for companies wishing to implement it, and that the by-products produced are less or almost not harmful to the environment.

Bacteria: Numerous bacterial genera possess the metabolic resources necessary to break down pesticides. Pesticide molecules may be utilized as electron donors or as nutrients during this process; the rate of metabolism will be influenced by a number of biotic and abiotic variables, including temperature, the availability of water and nutrients, the presence of other microorganisms, and the physical disturbance of the soil caused by agricultural practices. A highly poisonous material is transformed into a less harmful or even non-toxic product as a result of the bacterial pesticide biodegradation process. Organochlorine are organic compound containing at least one covalently bonded chlorine atom and are insecticides containing primarily of carbon, hydrogen and chlorine. These include a chlorocarbon, chlorinated hydrocarbon, organochloride, organochlorine or chlorinated solvent. Organochloride pesticides are synthetic. Certain pesticides, such as dieldrin and DDT, are persistent and build up in the environment for many years. They also get into food chains and continue to build up for decades after being applied to the soil. It is established that pure cultures can degrade organochlorine herbicides in situ. The majority of microorganisms engaged in the breakdown of organic chlorides are bacteria, particularly soil inhabitants of the genera *Bacillus*, *Pseudomonas*, *Arthrobacter and Micrococcus*. According to Matsumura *et al*. (1982), there is proof that Pseudomonas sp. breaks down dieldrin in the soil. The biodegradation of organic chlorine insecticides has also been demonstrated by studies with fungi.

Fungi: Fungi are more commonly utilized for bioremediation in soil than in water because they exhibit mycelial development. They also have the ability to synthesize enough extracellular enzymes to

generate the enzymes required for bioremediation. It must be underlined that the correct conditions, including pH, moisture content, and the presence of minerals, are necessary for the fungus to properly degrade the xenobiotic chemicals in the soil. One of the primary soil bioremediating agents against xenobiotic compounds is basidiomycetes. Their bioremediation approach is based primarily on the synthesis of extracellular ligninolytic enzymes, which transform harmful chemicals from complex to simple ones and provide energy and nutrition. They are distinguished by their high degradation capacity. The variety of chemicals including pesticides, polychlorinated biphenyl (PCB) and polycyclic aromatic hydrocarbons (PAH) are degraded by well-known fungus, *Phanerochaete chrysosporium*. Which is well known for xenobiotic metabolism and it was reported to have the ability to degrade isoproturon herbicide via solid state fermentation. Endosulfan degrading, aerobic fungal strains are effective for remediation of soil contaminated with organochlorine pesticides.Water body and soil that are affected by endosulfan can be easily bioremediated by *Aspergillus niger*. The fungus, *A.niger* was tested for their endosulfan degrading ability and it was noted that the culture could tolerate 400 mg/ml of technical grade endosulfan and the complete disappearance of endosulfan was seen after 12 days of incubation (Bhalerao and Puranik, 2007), which was indicated by the evolution of CO_2. Change in pH of culture broth to acidic range supported the biological transformation. Fungus uses chlorpyrifos as a sole energy and carbon source and causes its rapid degradation. Another fungus, basidiomycetes, degrades chlorpyrifos very effectively. The fungal strains such as *Fusarium oxysporum*, *Lentinulaedodes*, *Penicillium brevicompactum* and *Lecanicilliumsaksenae* has great potential for the biodegradation of the pesticides including difenoconazole, terbuthylazine and pendimethalin in batch liquid cultures and are investigated to be valuable as active microorganisms for pesticides degradation. Besides these, various fungal species including *Trametes* sp. and *Polyporus* sp. were able to degrade variety of chemicals including pesticides. Pesticide degradation ability was also reported using *A. fumigates*, *A. sydowii*, *A. terreus*, *A. flavus*, *Fusarium oxysporum* and *Penicillium chrysogenum*.

Algae: According to Garcia-Galan (2020), algae may and ought to be cultivated in aqueous conditions, in contrast to fungus and bacteria. Algae are unique in that they can thrive in poor water quality, which would severely impair the growth of other microbes due to extreme stress. Because of their metabolic adaptability, algae can use effluents contaminated with heavy metals, pesticides, or organic matter and turn them into a source of nitrogen (N), removing excess nitrogen from the environment. Algae are effective bioremediation agents of contaminated water, whether it comes from the industrial, residential, or agricultural sectors. They are also capable of producing oxygen (O_2) and sequestering carbon.

Table 1: Pesticide Degrading Bacteria

WHO Pesticide Classification	Pesticide	Bacteria
Extremely Hazardous	✓ Aldicarb ✓ Terbufos ✓ Methyl parathion	*Micrococcus arborescens, Pseudomonas aeruginosa, Nodularia linckia, Nostoc muscorum, Acinetobacter* sp., *Bacillus* sp., *Proteus* sp.
Highly Hazardous	✓ Cyfluthrin ✓ Tefluthrin ✓ Carbofuran	*Bacillus* sp., *Brevibacterium aureum, Burkholderia cepacia* PCL3, *Moderately Hazardous* S1
Moderately Hazardous	✓ DDT ✓ Permethrin ✓ Dimethoate ✓ Chlorpyrifos	*Streptomyces* sp., *Stenotrophomonas maltophilia, Acinetobacter calcoaceticus, Bacillus subtilis, Enterobacter ludwigii, Corynebacterium* sp., *Micrococci* sp., *Weissella confusa*
Slightly Hazardous	✓ Glyphosate ✓ Metolachlor ✓ Atrazine	*Pseudomonas balearica, Pseudomonas indica, Bacillus atrophaeus, Holophaga foetida, Rhizobium* sp.

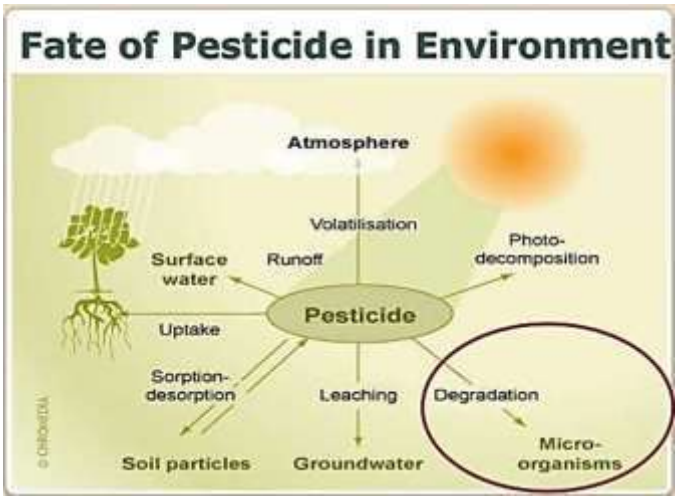
Table 2: Pesticide Degrading Fungi

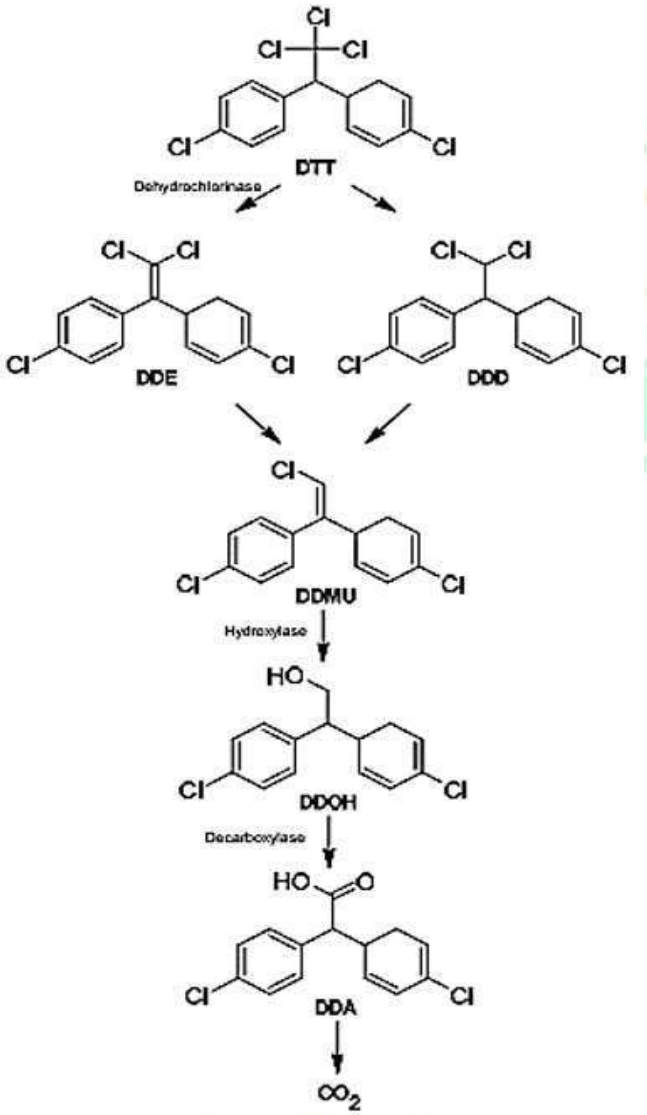
WHO Pesticide Classification	Pesticide	Fungi
Extremely Hazardous	✓ Aldicarb ✓ Terbufos ✓ Methyl parathion	*Trametes versicolor, Yarrowia lipolytica, Penicillium decaturense, Aspergillus sydowii, Ascochyta* sp., *Penicillium citrinum*
Highly Hazardous	✓ Cyfluthrin ✓ Carbofuran	*Ascochyta* sp., *Trametes versicolor, Mucor ramannianus, Pichia anomala*
Moderately Hazardous	✓ DDT ✓ Permethrin ✓ Dimethoate ✓ Chlorpyrifos	*Verticillium* sp., *Aspergillus* sp., *Trichoderma viride, Aspergillus niger, Trametes versicolor, Emericella* sp., *Penicillium implicatum*
Slightly Hazardous	✓ Glyphosate ✓ Metolachlor ✓ Atrazine	*Trichoderma* sp., *Trametes versicolor, Bjerkandera adusta, Metarhizium robertsii*

Microbial Enzyme Systems in Pesticide Biodegradation

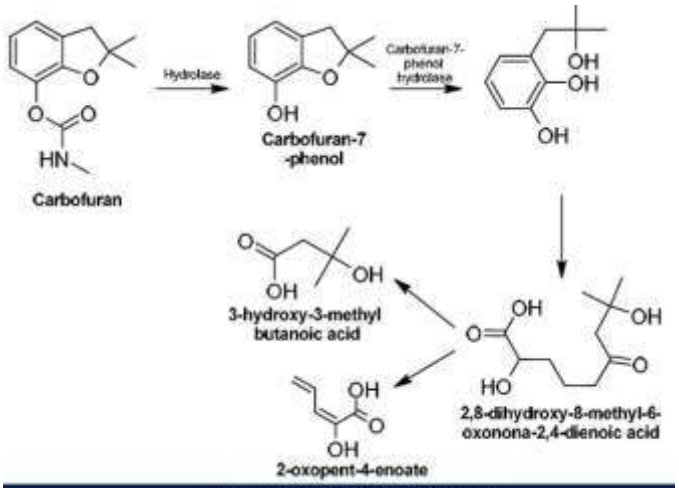
Enzymes are a crucial component of the biodegradation process, one of the many methods the microbe uses to break down xenobiotic substances. Dehydrogenases, cytochrome p450, dioxigenases, and ligninases are among the several enzymes that facilitate the metabolic reactions necessary for degradation. Numerous research have confirmed that various fungal species are capable of breaking down organochlorines. It has been discovered that bacterial enzymes can produce these detoxifying effects. The commonly used as a detoxification mechanism, especially in plants and insects, is conjugation with glutathione and this mechanism has also been reported in bacteria. In these processes, bacteria and fungi are involved. They produces intracellular or extra cellular enzymes such as hydrolytic enzymes, oxygenases and peroxidases. It has been reported that a large group of bacterial genera are able to degrade organophosphates compounds. Hydrolysis is fundamental for the complete degradation of the molecule. The reported and studied enzymes are related to the phosphotriesterase, having capability to hydrolyzing organophosphate pesticides at the central atom of pesticides, phosphorus. Phosphotriesterase activity is the first and most important step in detoxification. A large number of bacterial genera

have been reported for the carbamate degradation.





DDT Degradation Pathway



Carbofuran Degradation Pathway

Conclusion

One promising strategy for reducing the harmful effects of pesticides on the environment is pesticide bioremediation. Using microorganisms like fungi, bacteria, algae, and actinobacteria all of which are highly promising candidates to be employed as bioremediating agents of pesticides bioremediation can be accomplished. This technique can produce a variety of economically significant compounds, including bioplastics, biogas, and fertilizers. New technologies could help achieve an effective pesticide biodegradation process. The use of nanoparticles to deliver pesticides is an alternative where a more precise quantity of pesticide is used, and due to the chemical and physical properties of the nanoparticles, biodegradation by the action of microorganisms could be more efficient.

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Aquaponic System

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Introduction

The need to continuously develop alternative farming methods has always been important, especially in response to the multiple problems faced by conventional agriculture. Various organizations such as European Union, the Environmental Protection Agency, and the WHO often recommend the use of recycled water for irrigation, as a suitable solution for formulating water management strategies. According to studies, Hydroponic systems can be utilized to both produce food and treat wastewater (Sundar *et al*., 2021). They are a simple technology that enables the soil-free growth of plants in water. Plants get the nutrients they need for growth from the aqueous solution. Because plants can absorb nutrients, toxic metals, and emerging pollutants, the hydroponic system may also be utilized as a management technique before partially treated effluent is released eventually into the environment. Aquaponics is a new technology that combines the production of fish and plants. It is made up of two subsystems: hydroponics and aquaculture. The idea is to exchange nutrient resources between plants and fish and to use water efficiently to grow two crops. This farming method is mostly used to cultivate fish and vegetables in an integrated system in urban and resource-constrained settings. Fish and horticultural plants are raised together in aquaponics. Numerous plants can be grown in aquaponics systems; the most appropriate ones will vary depending on the system and the fish's maturity and stocking density. Capsicum, tomatoes, lettuce, cabbage, spinach, basil, chives, herbs, and watercress are examples of green leafy plants that are well suited to aquaponics systems and have low to medium nutrient requirements. In essence, it is a recirculatory culture. Despite the system's high initial cost, it has lower ongoing costs and provides respectable returns. The benefits of this technique are reduced labour, waste renewal, water use, and land area. Both plants and animals live in harmony with one another in an aquaponic system. The fish excrement gives the plants nutrients, while the plants clean the water, making it a favorable environment for the fish to thrive. Aquaponics is the food production method of the future. Reports state that aquaponic Systems only require 4-10% of the water required for traditional vegetable or crop cultivation, and they can produce ten times as much without the use of hazardous chemicals, pesticides, and other chemicals. Because it requires very little room, aquaponics is often referred to as “Urban Aquaponics,” “Urban

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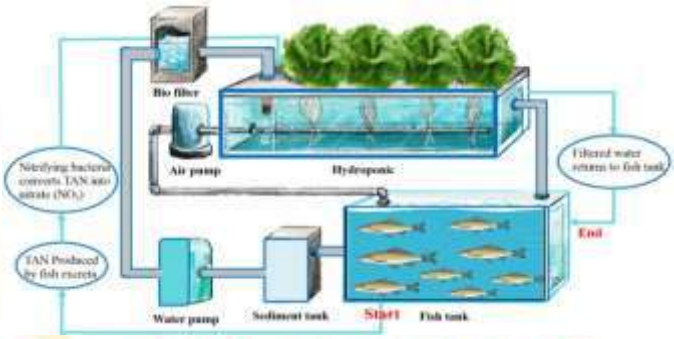
Agriculture," "Urban Farming," "Urban Gardening," "Urban Terrace Gardening," "Vertical Gardening," "Office Farm" (indoor), etc. for this reason. Using a water-recirculating system that mimics a natural ecosystem, aquaponics is a cutting-edge and environmentally friendly method of producing food. Aquaponics offers other benefits that consumers value in addition to the production technology's clean and safe and eco-friendly qualities. These benefits include being small-scale, locally grown, and naturally organic (Jayachandran *et al*., 2022).

Species Culture in Aquaponics

Halophytes like glasswort and rock samphire, as well as euryhaline fish species like sea bass and sea bream that can withstand a broad range of salinities, are beneficial for brackish water aquaponic systems. In aquaponics, nitrogenous products are decreased using systems such as the Self-sufficient Integrated Multitrophic Aquaponic (SIMTAP). Because seabass and seabream can grow in a variety of salinities, they are ideal for brackish water aquaponics. Although carps, tilapia, and catfish are more frequently utilized, species like *Colossoma macropomum* and *Clarias gariepinus*, which can adapt to a variety of diets, are equally promising. In addition to factors like environment, system type, and genetic material accessibility, market demand also affects the choice of fish species. Common aquaponic species include rainbow trout, Nile tilapia, barramundi, carp, and African catfish, as well as vegetables like tomatoes, lettuce, and basil. The most popular combination in aquaponics is tilapia and lettuce. Tilapia have been successfully raised in aquaponic systems due to their rapid development, resistance to disease, and capacity to tolerate a range of environmental factors. According to the results of a later poll, the majority of aquaponics producers, hobbyists, and educators (57%) employed tilapia, and the most popular plant crop among them was lettuce (83%). Intensive tilapia cultivation and hydroponic lettuce make an attractive combination, and many aquaponic farmers in the US are utilizing this technique (Hussain and Brown, 2024).



Advantages of Aquaponics Production System

Water conservation: Large-scale production of food fish is generally done in small or limited locations water used for commercial-scale fish farming is periodically changed to minimize harmful and detrimental impacts on the fish raised. The water renewal procedure is incredibly ineffective in getting garbage out of the system. At high concentrations, the water quality deteriorates and the health of the fish is impacted as bacteria further convert the ammonia into nitrate. The aquaponics production system's large-scale fish production, which involves co-rearing plants, aids in the water's nitrate absorption. Consequently, this introduces the idea of conserving and reusing water instead of continuously

replacing it with fresh water.

Improved growth rate and yield: It is clear that the adoption and commercialization of a sustainable food production system like aquaponics could improve food production in a relatively short amount of time and to a higher standard than what is currently achieved with a conventional system because the system depends on sustainable nitrogen cycling practices and continuous watering of the plants with nutrient-rich wastewater. It's getting more and harder to improve traditional farming methods to satisfy the growing geometric needs of the world's population.

Pollution reduction and energy consumption: Because they completely remove soil structure degradation and the pollution that goes along with it, aquaponics production methods are also more environmentally friendly than traditional conventional food systems (Okomoda *et al*., 2023).

Biodiversity Conservation: Traditional aquaculture practices can sometimes lead to environmental degradation and harm to local ecosystems. Aquaponics, by contrast, promotes biodiversity and ecosystem health because in this system, decreasing chemical inputs helps in reducing the environmental impacts associated with traditional farming practices. The integrated approach ensures that the balance between fish and plants is maintained, reducing the risk of diseases and pests. By incorporating aquaponics into agricultural practices, communities can exploit the benefits of a recirculatory system that conserves water, minimizes environmental impact, and contributes to sustainable land-water utilization in the face of land-water scarcity.

Present Scenario of Aquaponics Farming in India

Commercial aquaponics has gained significant momentum in recent years in India, with notable increases observed in states such as Maharashtra, Karnataka, and Kerala. According to a study, over 200 families in Cherai, Kerala, actively engaged in aquaponics farming. Various cultivation methods are being implemented at the Nanniode Aquaponics Research and Development Centre (NARDC) in Palakkad, Kerala. Prakruthi Aquaponics, a dedicated voluntary group, initiated the setup of an Aquaponics unit at the Coconut Nursery in Thiruvananthapuram, Kerala. Mori, a small village known for cashew exports in the East Godavari district of Andhra Pradesh, is transforming into a 'Smart Village' through collaborative efforts by the Innovation Society of the A.P. Government and the Garwood Centre for Corporate Innovation at the University of California, USA, and Swedish communication technology firm Ericsson. Their proposed 'Connected Aquaponics' and ‘Smart Water Grid Management’ IoT solutions combine aquaculture and hydroponics, creating a sustainable cycle by recycling ammonia-rich wastewater back to the aqua farm. In India, two well-known aquaponics farms are “Red Otter Farm” and “Madhabi Farm.” Red Otter Farm, a 10,000-square-foot aquaponics farm in Kotabagh, Uttarakhand, is one of the fastest-growing in India.

Madhabi Farm, a Bengaluru-based company, began production in 2017 and created "Satvik Sabji" in partnership with Waterfarmers, a Canadian company. In 2016, Sushant Madaan established the first aquaponics farm in North India, called Urban Kheti, in Gurugram, Haryana. That farm produces soft herbs like basil, mint, and coriander, as well as vegetables like tomatoes and lady fingers. Parag Thakkar, Parul Thakkar, and Pardeep Vedi founded "India Aquaponics" in Chandigarh in 2013. They created an aquaponics monitoring system that users may use from anywhere and receive real-time internet information. Aquaculture engineering dept. of IIT Kharagpur set up an NFT aquaponics system in which Ashwagandha, Brahmi, Sweet Leaf, Chili Pepper, lettuce, and Giloy are famed with tilapia fish for experimental purposes. Alternative Green Energy Solutions Private Limited, Agro Labs, City Greens, Radongrow India are some major companies involved in manufacturing hydroponics and aquaponics set up to support hydroponics and aquaponics farming in India.

Conclusion

The adoption of sustainable techniques is essential as India looks to expand its aquaculture industry. Aquaponics is a unique method for greening the Blue Revolution since it provides a comprehensive and environmentally responsible method of raising fish and vegetables. India can improve rural livelihoods and food security by adopting this cutting-edge approach, and it may also support international initiatives to build a more resilient and sustainable food production system. The aquaponics production technique, which combines a recirculating aquaculture system with soilless plant cultivation (hydroponics), is unquestionably an environmentally beneficial choice for 21st century food production. Despite the system's years of development, there are still a lot of study topics that need to be explored in order to yield knowledge that can aid increase fish and plant output at the same time.

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Application of Artificial Intelligence in Insect Pest Identification

Neha Pathak, Uma Sharma and Shantanu Kumar

Introduction

Many nations are built on agriculture, which is also crucial to a country's economic growth. The global population is expected to increase significantly by 2050, with estimates suggesting an addition of approximately 2 billion people. This growth will bring the total population from the current 7.3 billion to around 9.5 billion. As global pop ulation is on constant increase, the pressure on agricultural systems to meet the growing demand for food is escalating. As per the World Health Organization, there is need of 70% increase in food production to meet the food demand of approximately 10 billion people by 2050 (World Health Or ganization, 2018). Owing to this, there is need for scientific interventions to boost crop yields and link the gap between food production and consumption needs. of all the stressors, biotic stressors primarily weeds and insects cause significant losses in crop output, which account for 33% and 26% of total losses, respectively (Lal *et al*., 2017). With the world's population predicted to reach 9.8 billion people by 2050, insect pest outbreaks brought on by climate change are predicted to worsen agricultural losses, especially affecting the availability of food in communities that are already at risk. Today, modern agriculture is facing great difficulties. Agricultural manufacturing has now become a competitive and globalized industry where farmers and other actors providing input into agriculture have to consider climatic and geographical differences as well as global economic and political factor. Agricultural pests cause between 20 and 40 per cent loss of global crop production every year as reported by the Food and Agriculture Organization. The rapid spread of plant viruses even can cause epidemics, particularly in perennial trees where losses are compounded by the time and cost associated with re-establishment (Naidu *et al*., 2014). These concerns underscore the need for advanced tools to manage biotic stresses, especially insect pests during the cropping season. Accurate and timely pest identification is critical for implementing sustainable pest management strategies. Traditionally pest identification relies on expert knowledge, which is labour-intensive and not easily scalable. To support early pest detection and forecasting, digital technologies such as artificial intelligence (AI), internet of Things (IoT), machine learning (ML), and deep learning (DL) have entered the agricultural

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landscape. Artificial Intelligence (AI) is the field focused on developing algorithms and models to empower machines or computer systems with the capacity to execute tasks typically requiring human intelligence. From recognizing patterns in data to complex tasks like language translation and image analysis, AI spans a spectrum of applications. Its transformative potential lies in simulating human cognitive functions, revolutionizing industries, enhancing automation, and tackling intricate problems. AI-based image classification systems, coupled with machine learning and deep learning tools, are extremely helpful in identifying insect pests. These can extract the features from the images, interpret, and understand the visual information, and thus allow a system to improve its performance on a particular task (like- identification) over time.

Artificial Intelligence: An Introduction

The ability of computers to carry out tasks that normally call for human-like intelligence is known as artificial intelligence. The phrase "artificial intelligence" was first used in 1955, although the idea of AI dates back to the 1940s (Sujana and Augustine, 2024). AI is a field of computer science that focuses on building machines that can carry out operations like learning, reasoning, problem-solving, and perception that normally call for human intellect. Creating machines that can mimic human behavior by building ideas and reactions based on many scenarios and situations has always been the main goal of artificial intelligence. AI has a wide range of uses in industries like gaming, banking, healthcare, and education. AI encompasses several key characteristics. Foremost of them include Human-like Intelligence, as AI refers to the ability of machines to mimic human cognitive functions, such as learning from examples, recognizing objects, understanding language, making decisions, and solving problems. AI involves machine learning (ML), where machines learn from data and experiences to improve their performance. A subfield of machine learning, deep learning (DL) processes information similar to the human brain, using computer models to predict and classify information. Techniques such as machine learning, deep learning, and big data, are powerful in applications requiring system modeling and future prediction based on past data. In the current scenario, there is an exponential increase in data leading to role of AI in analysis and management of this vast amount of data.

Artificial intelligence and entomology: the parallelism

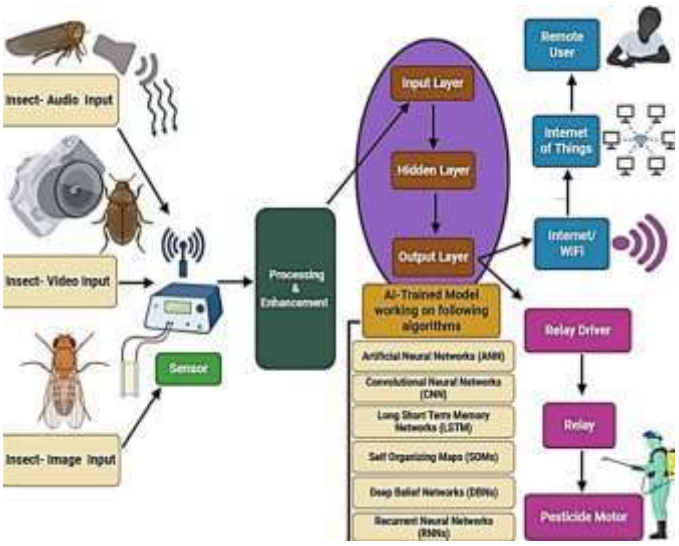
Because AI can automatically extract pertinent information from big and complicated datasets, it has become a useful tool in entomology. Because of this feature, it is especially useful for

ecological research, pest management and taxonomic research. An overview of the main fields in entomology where AI technologies are contributing significantly and could spur further advancements is given in this section.

Identification and classification of insects: Correct identification of insect pests and taxonomic classification through image-based detection has several advantages such as high efficiency, low cost, easy operation, and most importantly, this can provide necessary information to farmers to take effective measures against that pest. There are various methods available for detecting insect pest and diagnosis using images, such as threshold, edge, region testing and graph theory. However, these methods are only suitable for a few sample images and may not be accurate enough. Deep Learning (DL) can overcome these disadvantages and is becoming increasingly popular in in sect pest detection (Li *et al*., 2021).

Assessing Physical Attributes and Growth Prediction: To select healthy and diseased insects, the farmers follow manual methods like checking physical body factors, size, and weight, especially in sericultural farms. Using computer vision and deep learning models, entomologists have not only examined the physical attributes but also prepared a growth pattern based on the correlation between the insects' body size and weight. One Single Shot Detector-MobileNet-based (SSD-MobileNet) model was created to measure the size of Black Soldier Fly (*Hermetia illucens*) pupae and recommend whether they are suitable for breeding in order to prepare animal feed.

Observation of Insect Behaviour: The ethology of insects is characterized by different phenomena such as locomotion, feeding, mating, *etc*., and the ecologists take the corresponding observations for further studies. However, taking direct field observations is a tedious and highly constrained job (Dell *et al*., 2014). Insects may behave differently inside a laboratory compared to open field conditions and entomologists face huge difficulties in observing such behaviours due to a lack of proper instruments. These are the areas where artificial intelligence models can be of assistance to researchers. A new field of study is made possible by the combination of AI and pollinator activity detection. AI makes it simple to see the quantity of pollinators that visit flowers at a specific moment and their behaviors, which makes it simple to illustrate the foraging pattern.



AI in Sex Determination of Insect: Identification of male and female insects is essential for taxonomic

and entomological research, which includes studies on mating and post-mating behavior, species identification, and examination of antennal sensilla. Using high-resolution photos, artificial intelligence can help distinguish between male and female insect species. Additionally, AI techniques are able to differentiate between the pupal phases of both sexes.

Digitization of Insect's Specimens: Entomological specimen collection is the largest biological collection (Short *et al*., 2018). To effectively support the identification of species and taxonomic categorization, these insect collections were maintained in an organized and curated manner, ensuring that specimens were readily accessible for research and study purposes. Collections divided according to the method used for preserving insect specimens, as each preservation technique requires different archival conditions. The process of creating an electronic representation of materials or specimens is known as digitization. Sections of several insect collections are currently being digitized, which increases the accessibility of specimens and the data they are associated with and increases their impact. Every year, the number of publications using digital specimen data has steadily grown. This data has been used for projects involving identification, taxonomy, systematics, evolution, biogeography, and biodiversity assessment. It has also been used for analyses of invasive species in specific regions, climate change, agriculture, and species conservation.

Conclusion

The study of insect communities, including their population structure, habitat preference, and behavioral biology, as well as for offering important insights into their ecological roles, has benefited greatly from the use and integration of cutting-edge computer technologies and artificial intelligence in the field of entomology. The efficiency and accuracy of species identification and population monitoring have been significantly improved by a number of technologies, including DNA barcoding, computer vision, sound or acoustic analysis, remote sensing, and LiDAR technology. These technologies are also helpful for the study of behavior and ecology in both natural and lab settings. The rapid advances in neural network architectures have enabled a diverse array of models to achieve impressive accuracy in classifying and detecting insects. In this study, the performances of several AI models used in open fields, traps, and trap baseplates are analyzed, and it is evident that AI is no longer limited to experimental conditions but is gradually moving towards practical field applications.

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Leafy Vegetables: Factories of Antioxidants and Phytochemicals

Pooja Chak, S. Sailaja and Vinayaka K. S.

Introduction

Leafy vegetables constitute a crucial component of human diets globally, recognized not only for their micronutrient density but also for their abundant phytochemicals and antioxidants. These bioactive compounds contribute to mitigating oxidative stress-induced cellular damage by neutralizing free radicals, thus reducing the risks of chronic diseases such as cardiovascular disorders, cancer, and neurodegenerative conditions. Recent advances in phytochemical profiling and antioxidant capacity assessments have elucidated the complexity and richness of compounds contained within leafy vegetables, positioning them as natural biochemical factories that produce diverse compounds beneficial to human health.

Phytochemical Complexity in Leafy Vegetables

Phytochemicals, secondary metabolites produced by plants, are predominantly responsible for plants' defense against environmental stresses and pathogens. Leafy vegetables are especially enriched with several classes of these compounds, including phenolic acids, flavonoids, carotenoids, and vitamins, which act synergistically as antioxidants. Recent metabolomic studies have identified that common vegetables such as lettuce (*Lactuca sativa*), spinach (*Spinacia oleracea*), kale (*Brassica oleracea* var. *acephala*), and indigenous varieties contain elevated concentrations of phenolic acids such as ferulic, caffeic, and chlorogenic acids, alongside flavonoids like quercetin, kaempferol, and rutin (Nurzyńska-Wierdak, 2025; Mungofa *et al.*, 2022). For instance, red leaf lettuce varieties contain higher anthocyanin content than their green counterparts, which correlates with increased antioxidant activity, highlighting genetic variation's role in phytochemical profiles (Nurzyńska-Wierdak, 2025). Carotenoids such as lutein, beta-carotene, and zeaxanthin, prevalent in leafy greens like kale and spinach, not only function as antioxidants but also contribute to ocular health and immune function (Mungofa *et al.*, 2022). Vitamins C and E present in these vegetables act as potent antioxidants by directly scavenging reactive oxygen species and regenerating other antioxidants.

Antioxidant Capacity and Biological Functions

Oxidative stress results from the imbalance between free radical production and antioxidant

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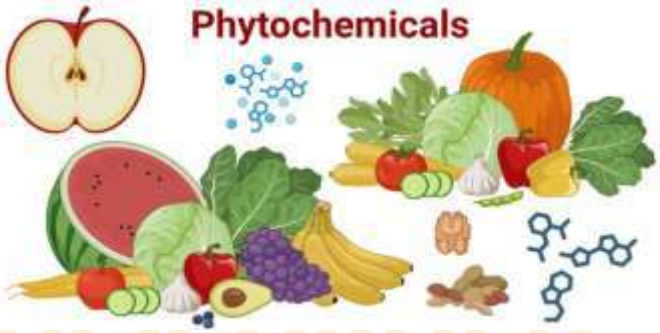
defense systems, leading to lipid peroxidation, DNA damage, and protein oxidation. Leafy vegetables provide several natural antioxidant compounds capable of restoring this balance. Multiple in vitro and in vivo studies demonstrate the radical scavenging activities of leafy vegetable extracts. Phenolic compounds exhibit strong activity against DPPH and ABTS radicals, while flavonoids inhibit enzymes like cyclooxygenase (COX-1 and COX-2) involved in inflammatory processes (Nurzyńska-Wierdak, 2025). Methanolic extracts from vegetables such as amaranth and Indian spinach show enhanced antioxidant activity post cooking, particularly frying, which possibly facilitates the release of bound phytochemicals and formation of novel antioxidant compounds (Annabhathula *et al.*, 2025). Antioxidants in leafy vegetables contribute to protective effects against chronic diseases by reducing low-density lipoprotein oxidation, modulating inflammatory pathways, and enhancing cellular defense mechanisms (Mungofa *et al.*, 2022; Nurzyńska-Wierdak, 2025). Flavonoids have been shown to possess additional antiviral and antibacterial properties, which fortify the immune system (Mungofa *et al.*, 2022).

Impact of Culinary Practices: Cooking methods significantly influence the bioavailability and efficacy of phytochemicals and antioxidants in leafy vegetables. Thermal processing such as boiling and frying can enhance antioxidant activity through mechanisms including cell wall breakdown and Maillard reaction product formation, despite some loss of heat-sensitive vitamins like vitamin C. For example, frying green leaved amaranth resulted in over 100% increase in phenolic content and radical scavenging capacity, suggesting that culinary treatment can be manipulated to optimize health benefits. However, different leafy vegetable species respond variably to cooking, implying that tailored preparation methods maximize antioxidant throughput depending on the vegetable type (Nurzyńska-Wierdak, 2025).



Role in Disease Prevention and Health Promotion

The cumulative intake of antioxidants and phytochemicals from leafy vegetables is linked with decreased incidence of cardiovascular diseases, certain cancers, neurodegenerative disorders, diabetes, and age-related macular degeneration (Mungofa *et al.*, 2022; Nurzyńska-Wierdak, 2025). The molecular basis involves modulation of oxidative stress, inflammation, and cellular signaling pathways that regulate apoptosis, cell proliferation, and gene expression. Epidemiological evidence supports that diets rich in leafy greens improve cognitive function, promote bone density through vitamin K and calcium synergy, and aid in weight management via dietary fiber's modulatory effects on satiety and glycemic control (Summa Health, 2024;

Nurzyńska-Wierdak, 2025). The mechanisms linking leafy-green phytochemicals to reduced chronic disease risk operate primarily through antioxidant, anti-inflammatory, gene regulatory, and immune-modulatory pathways.

Antioxidant Activity and Oxidative Stress Reduction: Phytochemicals in leafy greens, such as flavonoids, phenolic acids, carotenoids, and vitamins C and E, possess strong antioxidant properties that scavenge reactive oxygen species (ROS) and reactive nitrogen species (RNS) responsible for oxidative damage to lipids, DNA, and proteins are key contributors to chronic diseases like cardiovascular diseases (CVD), cancer, diabetes, and neurodegeneration (Zhang *et al.*, 2015; Nurzyńska-Wierdak, 2025). By neutralizing these free radicals, phytochemicals help maintain cellular redox balance, preventing oxidative stress-induced pathogenesis.

Modulation of Inflammatory Pathways: Chronic inflammation underlies many chronic diseases. Leafy-green phytochemicals inhibit pro-inflammatory enzymes such as cyclooxygenase (COX) and lipoxygenase (LOX), thereby reducing the synthesis of pro-inflammatory mediators like prostaglandins and leukotrienes (Gunathilake *et al.*, 2018). For example, polyphenols interfere with arachidonic acid metabolism, suppressing key inflammatory cascades. Additionally, specific phytochemicals downregulate pro-inflammatory cytokines such as tumor necrosis factor-alpha (TNF-α) and interleukin-6 (IL-6). Flavonoids like quercetin and catechins from green tea inhibit TNF-α and IL-6 production, attenuating systemic inflammation linked to diseases such as arthritis, metabolic syndrome, and diabetes (Lew and Fleming, 2024).

Gene Expression Regulation and Cell Signaling: Phytochemicals modulate gene expression and intracellular signaling pathways that control cell proliferation, apoptosis, and survival. Certain flavonoids inhibit epidermal growth factor receptor (EGFR) signaling and downstream PI3K/AKT and MAPK pathways, which are often dysregulated in cancers, reducing tumorigenesis and promoting cancer cell apoptosis (Kaveh Zenjanab *et al.*, 2024). This gene regulatory effect also contributes to protection against oxidative-stress-induced cellular damage and supports cellular detoxification mechanisms.

Immune System Enhancement: Phytochemicals enhance immune function by stimulating immune cells such as macrophages and T-cells, improving the body's defense against infection and regulating inflammatory responses. They also promote a healthy gut microbiome, which is crucial for immune homeostasis (Lew and Fleming, 2024). Compounds such as beta-glucans and catechins boost immune

cell activity and improve recovery from infections, providing additional layers of protection against chronic disease progression (Van Doan *et al.,* 2024). In summary, leafy-green phytochemicals engage multiple complementary mechanisms-antioxidant defense, inflammation modulation, gene pathway regulation, and immune enhancement; forming a sophisticated network that reduces chronic disease risk at molecular, cellular, and systemic levels.

Wild and Indigenous Leafy Vegetables: Untapped Sources

Recent phytochemical screenings of indigenous leafy vegetables reveal richness in bioactive compounds comparable or superior to commercial varieties (Bhat *et al.,* 2013; Mungofa *et al.,* 2022). These wild species harbor unique alkaloids, saponins, and tannins with pharmacological activities, emphasizing the potential for discovery of novel therapeutic agents from underexplored plant sources (Nurzyńska-Wierdak, 2025; Bhat *et al.,* 2013).

Conclusion

Contemporary research highlights leafy vegetables as dynamic biochemical factories synthesizing a broad spectrum of antioxidants and phytochemicals that exert multidimensional health benefits. Their integration into daily diets offers a viable strategy for non-pharmacological intervention against oxidative stress-mediated pathologies. Moreover, understanding the influence of genetic diversity and culinary practices on phytochemical content paves the way for dietary optimization.

The expanding knowledge on indigenous leafy vegetables further enriches the reservoir of natural bioactive compounds with promising applications in nutrition and medicine. Continued research is essential to fully unravel the molecular intricacies and clinical potential residing within these verdant nutrient reservoirs.

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Art of Dried Flower Craft

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Introduction

The 21st century has been called the "Century of the Environment" with the current society facing the adverse effects caused by climate change, itself a product of global warming and increased environmental pollution. A healthy and sustainable future is expected to be constructed by proper policies, education, innovation in Green technology, and compatible relationships between the Governmental and Industrial sectors of a country. Floriculture is a branch of horticulture that is not only concerned with the growth of flowers and ornamental plants but also with their value addition and marketing. Floriculture is an intricate enterprise in India (Shelke, 2014). In the world of flowers, various segments play a part in the overall growth of the sector. From beautiful cut flowers and loose blossoms to plants for landscaping, fillers, indoor greenery, turf grass, and even seeds and planting materials - each of these elements contributes to the vibrant tapestry of the floricultural industry. Additionally, the inclusion of value-added products adds an extra layer of richness to the sector's overall growth. Beyond their aesthetic appeal, flowers and ornamental plants play a crucial role in shaping the environment of both urban and rural areas. They contribute significantly to the planning and beautification of spaces, and they are essential in the development of wastelands to combat pollution. In essence, they bring not just beauty but also environmental benefits to our surroundings. (Pandey *et al*. 2015). Flowers have always remained an integral part of man's life and love for natural flowers is an inherent instinct. Dry flowers have been used for decoration for a very long time. Worldwide, there is a sizable market for dried flowers as well. In every arrangement, dried plant materials balance out any office or home decor. A wide range of floral products for commercial usage can be made from dried flowers. As of 2003, the industry's estimated yearly turnover was above 150 crores. Seventy-one percent of India's flower exports are dry flowers, which are primarily sent to the United States, Japan, Australia, Europe, and Russia. As individuals become more environmentally concerned and select eco-friendly and biodegradable alternatives to fresh flowers, the market for dried flowers is expanding quickly worldwide. These dried flowers or foliages can be readily used to create a variety of decorative items, including greeting cards, segments, wall

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hangings, landscapes, calendars, potpourris, etc. Thousands of jobless men and women could be empowered by the labor-intensive dried flower industry. As a result, there are many opportunities to develop the dry flower sector and provide jobs, particularly for housewives, rural women, and those with physical disabilities.

Techniques of flower drying

The drying process or technique used has a significant impact on the quality and look of dried flowers and other decorative plant components. A variety of methods, including as air drying, press drying, embedding drying, oven drying, and freeze drying, are used to produce dried decorative plant material. One of India's first institutes dedicated to dehydrating flowers, greenery, and floral crafts is the NBRI in Lucknow. To keep flowers, twigs, branches, foliage, etc. looking fresh for months or even years, a variety of dehydration procedures have been devised (Mishra *et al*., 2003). The ultimate moisture level of dried flowers plays a crucial role in shaping the flowers and determining their longevity. The moisture content in dried flowers additionally impacts their lifespan, with an inverse relationship. Maintaining a moisture content within the range of 8-11.5 percent guarantees optimal quality, firmness, and longevity.

Air Drying: A common and economical method for conserving plant material is air-drying. This technique involves tying the plant material to a wire or rope and either leaving it in a dark spot or letting it dry in the sun. Other names for this method include "Hang and Dry" and "Upside Down" drying. An area that is heated, well-ventilated, low in humidity, and well-lit is ideal for air drying. This technique is frequently used to preserve flowers such as sunflower, chrysanthemum, salvia, globe amaranth, dry rose, larkspur, and statice. The drying plant material should not be exposed to wet conditions or direct sunlight. The drying process using this method usually takes two to three weeks to finish. Diaz-Maroto *et al*. (2003) revealed that air drying at ambient temperature produced fewer changes in aroma of parsley than the other drying methods like oven drying and freeze drying. Air drying was the most simple and cheap method as it depends upon atmospheric humidity, air velocity, moisture content of the flower, type and size of the flower.

Press Drying: The most prevalent technique for drying plant material involves sandwiching it between layers of absorbent paper, such as newspaper or blotting paper, and then applying

sufficient pressure to eliminate moisture. This method was initially documented in 1820 and subsequently adopted by botanists and herbalists for the creation of herbaria. The stacked sheets have a piece of cardboard with identical dimensions placed between them to facilitate the escape of water vapor. Flowers, such as rose, chrysanthemum, candytuft, lantana, euphorbia, verbena, and leaves like silver oak, fern, and thuja, are excellent choices for press drying. This technique is employed for flowers in cases where maintaining their shape is unnecessary.

Microwave Drying: Drying flowers with silica gel in microwave is a quick and efficient method. Fresh, preferably unopened flowers stems are trimmed to about 2 inches and any unwanted leaves are removed. In a microwave-safe container 1-2 inches deep layer of silica gel is laid. Flowers are gently placed with face up on top of the silica gel without overlapping. More silica gel is poured over the flowers until they get completely covered, making sure the flowers are securely nestled in the gel which is then placed in the microwave on high for 1-3 minutes. It is essential to microwave in short bursts of 1-minute intervals to check the flowers progress. After the flowers have been dried, they are gently removed from silica gel using tweezers. The flowers are then allowed to cool, and any remaining silica gel is carefully brushed off. Delicate flowers like roses, chrysanthemums, lilies, and violets work particularly well with this method.

Embedded Drying: Sand, borax, sawdust, and silica gel are examples of ambient desiccants that are essential to the embedded drying process since they absorb all of the moisture from the flowers as they are drying. These desiccants hasten the process of removing moisture while maintaining the blooms' organic shape. This method works even for flowers that don't dry well on their own because it cuts down the drying time to 5 to 8 days. Particularly suitable for this preservation technique are delicate flowers like dahlias, carnations, and roses.

Popular Dried Flower Craft Projects

Dried Flower Arrangements: Dried flower bouquets and arrangements offer an everlasting touch of nature to home decor. The unique texture and colors of dried flowers lend a rustic and timeless appeal to any space.

Pressed Flower Art: The art of pressing flowers between heavy books to flatten and preserve them has stood the test of time. Pressed flower art finds its place in various crafts, such as creating greeting cards, bookmarks, and framed botanical art.

Potpourri and Sachets: Crafting potpourri or sachets from dried flowers and aromatic herbs allows for delightful scents to fill the air, adding a touch of tranquility to any room.

Floral Wreaths: Dried flower wreaths have become a popular choice for seasonal decorations, weddings, and festive celebrations.

List of Plants Suitable for Dried Flower Crafts

There is a wide variety of plants suitable for dried flower craft, each offering unique colors, textures, and shapes. Here's a list of some popular plants commonly used in dried flower arrangements and crafts:

Roses (*Rosa* spp.): Roses, with their timeless beauty, dry exceptionally well and retain their elegant form and fragrance.

Baby's Breath (*Gypsophila* spp.): This delicate, airy flower dries to a soft, cloud-like appearance, making it a popular choice for adding volume to dried arrangements.

Statice (*Limonium* spp.): With its papery texture and vibrant colors, statice is perfect for creating long-lasting floral displays.

Lavender (*Lavandula* spp.): Known for its soothing aroma and delicate purple flowers, lavender is a favorite for dried flower crafts and potpourri.

Wheat (*Triticum* spp.): Dried wheat stalks are commonly used in rustic and country-style arrangements, adding height and a warm golden hue.

Globe Amaranth (*Gomphrena globosa*): The vibrant, globe-shaped flowers of this plant retain their color exceptionally well when dried.

Delphinium (*Delphinium* spp.): The tall, elegant spikes of delphinium add a touch of drama to dried arrangements.

Marigold (*Tagetes* spp.): Marigold flowers dry beautifully and can be used in various crafts, including potpourri and wreaths.

Dry flower Products

Potpourri is usually a combination of dehydrated, sweet scented plant portions with flowers, leaves, seeds, stems and roots. The source of a potpourri is the aromatic oils originated within the plant. It is of two types viz., dry and moist. The dry method is the most common, quicker and easier method but the disadvantage is it does not last for a long period. Both methods Fixative is needed for both methods for absorbing the aromatic oils and to release them slowly. The aromatic herbs used for perfumery such as Rosemary, Sage, Lavender, Artemisia, Thyme, Basil, Achillea (Yarrow), Scented Geranium, Mint, Marjoram, Verbena, Anise and Fennel. While drying the herbs and fruits, it should be thoroughly dried. Otherwise, it invites the problem of preventing mildew. Dry and pressed flowers can be used for preparing home decor products. The ideal way to use them is to make calendars, festive decorations, floral balls, floral crafts, greeting cards and covers, decorative wall hangings, and other artistic displays. Dry flower objects can be used to create floral albums for plant identification in botanical research. A cottage or small-scale business that specializes in dry flower home décor items made from dehydrated flowers,

leaves, fruits, pods, seeds, and other plant parts in a subtle manner. To shield them from dust, wind, and atmospheric moisture, dry floral products can be arranged artistically and covered with plastic or clear glass.

Conclusion

Dry flower technology is a great way to create self-employment, especially for people with artistic abilities and innovative ideas who want to create high-priced home décor items. Since it is composed of organic compounds derived from plants. It is a promising and efficient post-harvest technique for enhancing the decorative storage quality of plant and flower components. In addition to providing a pathway for the production of ornamental goods, it also helps increase foreign exchange earnings. Even though it had advantages, there are also some drawbacks, such as the produce's fragility, hygroscopic nature, and lack of long-term storage packaging methods, all of which call for extensive research to improve the methods in the aforementioned areas and create the greatest home décor items ever.

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Nanoscience in Plant Stress Mitigation

Md Sabir Ahmed Mondol, Mouli Paul and Ajay Baldaniya

Introduction

Food security remains a major concern for a country's long term and sustainable development. Sustainable agriculture is necessary to attain "Zero Hunger", one of the United Nations' 17 sustainable development goals. In the current global scenario, food production and distribution remain under severe strain because of the rising population, climate change, environmental contamination, and increased water and energy demands (Adrees *et al.* 2020). According to the FAO (2017), the world's population is expected to reach 10 billion by 2050, resulting in a 50% increase in food demand, particularly in developing nations. In developing countries, notably India, agriculture is one of the most essential components of the national economy. Increasing food production rates contribute significantly to the growth of the nation's GDP. In addition, more than 60% of the population relies on it for sustenance, fodder, fuel, and fiber. The decline in food grain productivity can lead to food scarcity and a decline in nutrition security. Limitations in water and agricultural land availability are attributed as major reasons for declining food productivity trends, while the deterioration of water, soil nutrients, climate change, and so on can accentuate this problem. The changing climate is a grave concern for the agricultural community as it causes numerous challenges during crop production. Das and Das (2019) reported around 70% yield loss through biotic and abiotic stresses. These stresses are challenging to manage because plants exhibit complex reactions, resulting in physiological, morphological, and metabolic changes. Unpredictable climate change and the emergence of various pests and diseases have notably reduced agricultural production, particularly in global cereal production like maize by 3.8% and wheat by 5.5%. Abiotic stresses imply the alteration of plant morphology, physiology, biochemical, and molecular changes due to osmotic, nutrient imbalance, hormonal, oxidative stress, and ionic toxicity. Water deficiency, leading to drought stress, further diminishes plant vitality. According to the US National Nanotechnology Initiative (NNI), nano-science presents a viable solution to these problems. It entails atomic or molecular manipulation of materials to produce structures with a variety of uses in research and development. An alternate avenue for research is provided by nanoscience, which offers a flexible and capable technology in nearly every area

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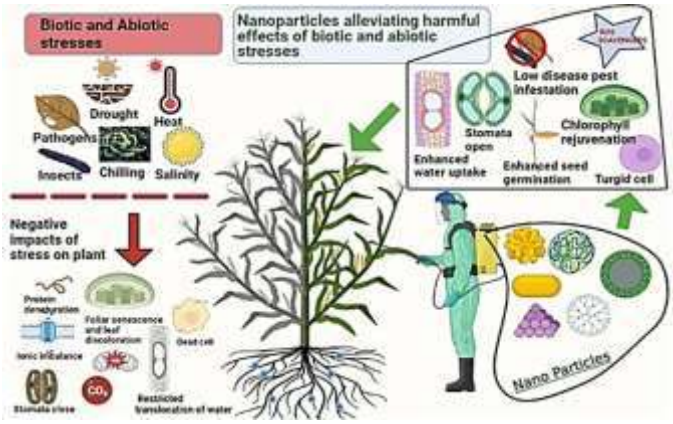
of biological science. An alternate avenue for research is provided by nanoscience, which offers a flexible and capable technology in nearly every area of biological science. These technologies can create new materials with exceptional properties by manipulating matter at atomic and molecular levels in the 1-100 nm size range.

Nanoparticle Application and Response to Abiotic and Biotic Stress: There are numerous innovative technological approaches to improve crops with higher yields under climate change, primarily abiotic and biotic stresses. The significant heterogeneity of plant response to various stressors necessitates the adoption of strategies that can improve performance and enhance the tolerance of plants to stress provisions in order to escalate food production with limited accessible land resources. The trend of population growth has accelerated, and by 2050, it will reach 9.1 billion. This is in line with the FAO 2050 vision, which states that the world must produce more food and address the challenges facing agriculture in the near future. Plants require light, carbon, water, and mineral nutrients, and by using them, they can survive under various environmental stresses. Abiotic stress affects the plant's physiological and biochemical phenomena, lead ing to changes in plant growth, flowering behavior, fruiting, and finally, causing a reduction of yields. The precarious situation arises when the stresses of drought, salinity, cold, temperature, submergence, flooding, and heavy metals transcend the tolerance limits within plants.

The significant abiotic stresses, i.e., drought had affected 64% of the global land area, followed by the cold, which affected 57% of the land area, 15% of acidic soils, 13% of the flood, 6% salinity, and 9% mineral deficiency area (Cramer *et al*., 2011). The application of nanobiochar on the growth dynamics and antioxidative responses in *Spinacia oleracea* plants under 50 mM NaCl and drought stress have been reported by Rasheed *et al*. (2024). They observed that the plants improved significantly on biomass, net assimilation rate, leaf area, photosynthetic pigments, and nutrient content under drought and salinity stress conditions after spraying the nanobiochar solution at 3% (w/v) at weekly intervals of 14, 21, and 28 days after sowing. They also noted that under drought stress conditions, the application of 3% nanobiochar increased about 62% in catalase activity, a two-fold rise in peroxidase activity, and a 128% increase in superoxide dismutase activity compared to the control (without nanobiochar). Nanobiochar application enhances membrane stability and reduces lipid peroxidation and electrolyte leakage under salinity stress.

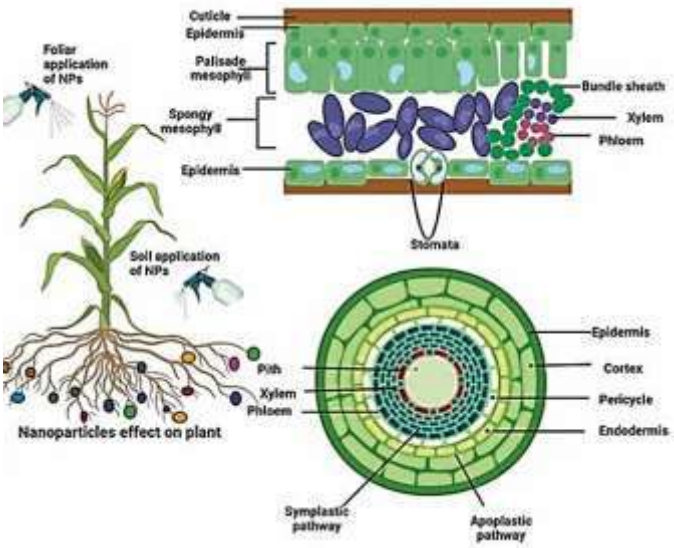


Mechanisms of Uptake, Translocation and Accumulation of Nanoparticles in Plants

According to Dang *et al*. (2021), one of the main ways that nanoparticles enter food chains is through contact with plants. Nanomaterials (NMs) differ greatly from bulk materials of the same composition due to their unique physicochemical properties, which include chemistry, shape, surface area, and surface charges. The uptake, movement, and expansion of NPs in plants are influenced by a range of physicochemical properties like surface chemistry, stability, chemical structure, and size vary across different plant species. Nanoparticles can enter plants through both air and soil. Aerosol nanoparticles may enter aerial parts of plants through stomata, wounds, or direct penetration via the aerial surfaces, while from soil nanoparticles can penetrate through root hairs and tears, lenticels, and other entry points. Numerous researchers have proposed plausible mechanisms and the significance of how nanoparticles are taken up, transported, and accumulated in plants. When plants are exposed to aerosol nanoparticles, many of these nanoparticles enter the plant leaves through cuticular and stomatal pathways. They accumulate within sub- stomatal regions and stomata and subsequently move to various plant parts through tracheal phloem system. NPs reach plant leaves via two distinct paths, the cuticular pathway and the stomatal pathway, per a study by Buick *et al*. (1993). The cuticle, the outermost waxy coat found in different parts of plant leaves, controls the exchange of solutes and shields the leaves from water loss. Because of this special quality, it serves as plants' first line of defense.

Various types of nanoparticles (NPs), including negatively charged mesoporous silica NPs (20 nm) and neutrally charged lipid-based liquid crystalline NPs (150 to 300 nm) have been observed to accumulate beyond anticlinal cell walls or within cuticle.

Role of Nanoparticle Under Drought: Reduced cell division and growth rates, longer stems and roots, smaller leaves, and problems with nutrition and water management are just a few of the negative effects of drought stress on plants. Crop yields may eventually decline as a result of these consequences. It has been shown that Si-NPs, ZnO-NPs, and hematite NPs increase plants' resistance to drought. Pomegranate plants' physicochemical characteristics, photosynthetic pigments, phenol and osmolyte concentrations, antioxidant enzyme activity, and nutritional status were all enhanced by Si-NPs (Zahedi *et al*. 2021).



Role of Nanoparticles in Mitigating Heavy Metal Stress: Heavy metals are persistent in the environment because they are non-degradable and

hinder plant growth. Mushtaq *et al*. (2020) found that iron oxide (FeO) nanoparticles in combina tion with Bacillus subtilis S_4 can increase the production of stress-alleviating poly amines in pumpkin seedlings experiencing arsenic stress. Pea seedlings are sensitive to chromium (Cr) toxicity, but Si-NPs can protect them by reducing Cr accumula tion and modifying oxidative stress, and increasing antioxidant enzyme activity.

Nanoparticle and Biotic Stress: NP-based silver formulations (Ag and Ag based composites) are toxic to microorganisms, especially fungi and having antimicrobial activity. Besides silver NPs, other zinc NPs, copper (Cu), titanium (Ti), gold (Au), and magnesium (Mg), have been extensively tested for their antimicrobial properties. As metal NPs have characteristic properties like high melting points, tough ness, catalysis, and coloration, they are now preferably used instead of enzyme labeling systems in phytopathogen diagnostics. Chowdhury *et al*. used both copper (CuNPs) and silver nanoparticles (AgNPs) having particle sizes rang ing from 306 to 375 nm against *Xanthomonas oryzae* and *Rhizoctonia solani* and observed that the nanocomposite for mulation has a significant role and improved stability (zeta potential-54.7 to 39.4 mV) than only the copper nano particle. They have studied in silico analysis and observed that proteins generated better complexes with CuNPs than AgNPs. They suggested that the copper and silver nanocomposites could be used to develop formulations to control the disease against rice crops.

Conclusion

It is essential to consider the world's future food needs and investigate fresh approaches to farming methods in order to boost output and guarantee environmental safety. To improve food security, integrated pest management techniques are required, and spending time on cutting-edge agro-nanotechnology is a respectable option. Precision farming and increased agricultural productivity are two benefits of nanotechnology, an integrated science. Using NPs as insecticides and fertilizers will more accurately control agricultural risks than any other strategy. Additionally, NPs are utilized as biosensors for nutrient and contaminant detection, effectively addressing biotic and abiotic stresses in plants. Silica-based nanocomposites have effectively reduced pest damage while promoting chlorophyll content, photosynthesis parameters, and seedling vigor. Nanosilicon demonstrates superior absorption efficiency compared to traditional silicon fertilizers, enhancing plant nutrient uptake and shoot growth. SiNPs have dominant illuminations and are required for immunosensor applications. It has antimicrobial properties because of its large surface area.

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Salicylic Acid Meditated Plant Defence

Md Sabir Ahmed Mondol, Tejas Kumar M. K. and T. C. Suma

Introduction

Any adverse circumstance or material that impairs a plant's growth, development, or metabolic processes is referred to as plant stress. Generally speaking, there are two primary types of plant stress: biotic stress, which is brought on by bacteria, viruses, fungi, and insects, and abiotic stress, which is brought on by environmental conditions including heat, drought, salinity, cold, waterlogging, and heavy metals. Global agricultural productivity is seriously threatened by abiotic pressures, and agricultural systems are deteriorating as a result of human activity. Abiotic stressors are predicted to have the ability to cut crop productivity by more than 50% and the yield of staple food crops by 70%. Therefore, it is crucial to improve plant performance and mitigate the loss of productivity caused by abiotic stress. One approach to achieve this is through the exogenous application of plant hormones. Plant growth regulators (PGRs) are organic compounds used to stimulate, inhibit, or modify plant growth and development. The main cause of the highest famines in many crop plants is plant pathogens, which include bacteria, viruses, fungus, and phytoplasma. Chemical and cultural fungicides were widely used to control plant diseases, which harmed the natural ecosystem and caused plants to become resistant to fungicidal treatments. Through a physiological and pharmacological mechanism, salicylic acid (SA), a plant-induced growth hormone, aids in the activation of defense pathways against a range of biotic and abiotic stressors. Salicylic acid is well known as a precursor of aspirin, the active ingredient of which is acetylsalicylic acid. Aspirin is among the oldest, cheapest, and most widely used medicines in human history; it is broadly used as fever-reducer, pain reliever, and anti-inflammatory medicine (Myers, 2007). Studies have shown that long-term use of aspirin may reduce the risk of stroke, cardiovascular disease, and heart attack. In addition, non-acetylated salicylate shows effectiveness in treating type II diabetes (Goldfine *et al.*, 2013). In humans, aspirin irreversibly inhibits cyclooxygenase 1 (COX-1) and modifies the enzymatic activity of COX-2, both of which catalyze the production of prostaglandin H_2 from arachidonic acid, involved in inflammation, and thromboxane A_2, involved in blood clotting. SA, one of the main hormones in plants, regulates a number of physiological functions, including fruit maturity, storage and seed germination.

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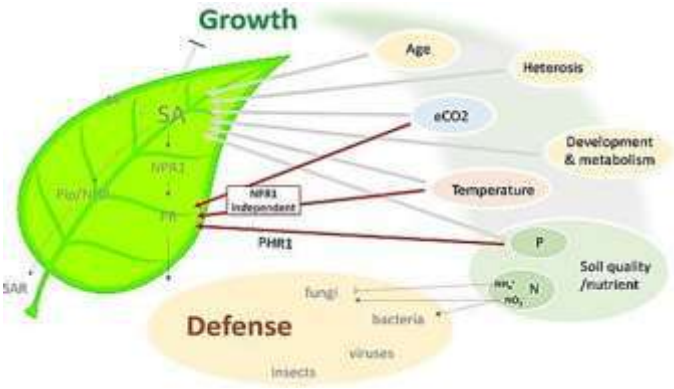
Furthermore, SA regulates stomatal mobility, photoperiod, sex differentiation, and flowering development. In order to trigger a defense response against infections, SA is both necessary and sufficient. It has been demonstrated that transgenic plants that overexpress the NahG transgene from Pseudomonas putida, which codes for SA-degrading hydroxylase, are more vulnerable to a range of infections.

Role of Salicylic Acid in Plants

- ✓ Enhances physiological processes and the efficient translocation of photosynthates toward reproductive organs, improving yield and productivity.
- ✓ Promotes plant growth and development, as well as ion uptake and transport.
- ✓ Stimulates cell division and differentiation, accelerating the formation of photosynthetic pigments and delaying leaf aging.
- ✓ Minimizes both biotic and abiotic stresses.

Source of Salicylic acid

Salicylic acid can be sourced from various places. It is naturally isolated from the bark of willow trees (*Salix* spp.), which contains salicin at levels of 9.5-11%. SA is found in the plant in the form of free phenolic acids or associated with amino compounds. Willow tree bark is particularly rich in SA and can be found near marshes and in sunny areas. It is native to China. It can also be synthesized, either through the biosynthesis of the amino acid phenylalanine or from phenol. Additionally, it can be extracted from natural sources like mango, broccoli, cauliflower, and tomatoes. Salicylic acid is available in both liquid and solid formulations.



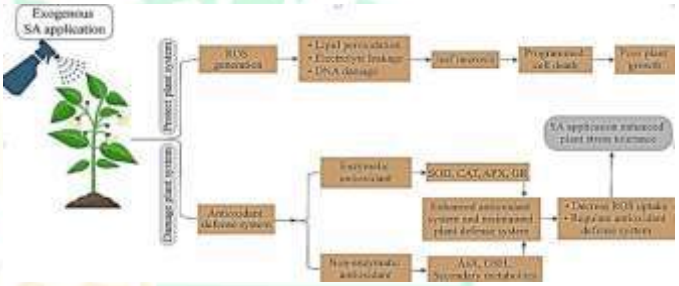
Systemic acquired resistance and Salicylic acid

During SAR, plants produce one or more translocated signals that activate the resistance mechanism in uninfected parts consequently the primary infection preconditions the plant to resist further attacks (Bektas and Eulgem, 2015). At the molecular level, SAR was shown to develop with the increased expression of a large number of pathogenesis-related (PR) gene families, in both local and systemic tissues following infection with TMV. These PR genes encode low molecular weight heterogeneous group of proteins that are also induced by exogenously applied chemical elicitors of plant defense. PR proteins were first reported in *Nicotiana tabacum* cv. Xanthi nc and N.t. Samsun NN in TMV-infected leaves. Most of the defense responses mediated by PR proteins have been characterized in tobacco, Arabidopsis, and cucumber plants. PR proteins are widely used as mo lecular markers of the SAR responses in plants. A recent study suggests that PR1 protein binds and sequesters host sterols that are required by the pathogens for their growth. The sterol-binding activity of PR 1 protein reveals the

Table 1: Major functional analogs of salicylic acid (SA) that activate plant defense via SA-mediated signaling

Chemical Inducer	Type	Mode of action
Salicylates and its derivatives (3,5-dichlorosalicylic acid, 4-chlorosalicylic acid, and 5-chlorosalicylic acid)	Primary signal	Critical signal to express SAR in most plants against pathogens
INA (2,6-dichloro-isonicotinic acid)	Synthetic SA analog	Induces SAR genes by activating defensive signal downstream of SA. It interacts with NPR1 related proteins
NCI (N-cyanomethyl-2-chloroisonicotinamide)	Synthetic SA analog	Induces SAR by triggering defense signaling steps operating between SA and NPR1
DCA (3,5-dichloroanthranilic acid)	Synthetic SA analog	Works at WRKY70-dependent step of the SA defense signaling network with no requirement of NPR1

mode of action of an antimicrobial protein. In addition to PR gene family expression, SAR also needs SA accumulation. In infected host tissues, the SA level rises locally and decreases systemically. First identified in willow tree bark extracts, salicylic acid (called after the Salix plant) has been used as an anti-inflammatory medication since the 18th century. Acetylsalicylic acid's anti-inflammatory qualities were added to aspirin by the Bayer Company in 1897. Tobacco plants treated with aspirin were more resistant to tobacco mosaic virus (TMV) infection in the future. Later studies showed that the treatment of plants with aspirin also leads to the accumulation of PR proteins. The importance of SA in SAR signaling was shown by the subsequent experiments with transgenic plants overexpressing a bacterial salicylate hydroxylase gene (the nahG gene) that effectively reduces the level of endogenous SA and makes the plant susceptible to diseases. Earlier labeling studies in TMV-infected tobacco and cucumber showed that SA is mobile during induction of SAR and most of the SA accumulates systemically in upper non-infected leaves of infected plants. It was noticed that SAR induction by an infecting pathogen could only be effective for subsequent pathogen infection and most times the f irst SAR-inducing infection causes enough damage in plant tissues. It implies that SAR induced by the pathogens have less effect on disease resistance rather than if it is activated before the pathogen attack (Conrath *et al*., 2015).



Mechanism of activation of Salicylic acid in defense against Plant Pathogen: Salicylic acid is mediated through two compartmentalized pathways that originated from different precursors; phenyl-propanoid pathway from phenylalanine in the cytoplasm and isochorismate pathway in the chloroplast. The activation of SA could also be converted to MeSA (methyl salicylate) by the enzyme SA carboxyl methyltransferase and this helps in long distance signal activation in plants and is called Plant Induced Salicylic acid mediated Systemic Acquired Resistance (SAR). SAR is typically characterized by a restriction of pathogen growth and suppression of disease symptom develo-

pment compared to non-induced plants infected by a similar pathogen. The onset of SAR is associated with increased levels of SA both at the infection site and systemically. SAR is associated with the coordinate activation of a specific set of genes encoding pathogenesis-related (PR) proteins, some of which possess antimicrobial activity.

Conclusion

Since most elicitors are structurally and/or functionally similar to salicylic acid, it is essential for defenses triggered by synthetic compounds. In plants, SA-mediated defense signaling is part of a multi-step coordinated defensive process. These substances cause plant immunity by interacting with the SA pathway at various stages. We shall obtain more elicitors and their derivatives by further screening of plant elicitors. The activation of SAR provides a broad-spectrum resistance against a wide range of related or unrelated pathogens. There has been considerable progress in the biochemical and molecular understanding of SAR activation in various plants. In addition, several chemicals including SA and its analogs are known to provide a direct or indirect defense against pathogens when applied to plants. Molecular mechanism of plant defense induced by synthetic chemical inducers is not very well understood.

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Women's Empowerment and Gender Equality in Agripreneurship

Shilpa Naik, Ragini Modi and Shraddha Kapadiya

Introduction

Latin words "Ager" (land or field) and "culture" (cultivation) defines the "agriculture" which is a field of science of crops cultivation for self-consumption and economic gains. Cultivation for economic gains after self-consumption is the most ancient science related to cultivation of crops. The natural environment and need for food resources for feeding increasing population are the main engine for human energy in urbanization. It provides human resources for livelihood promotions and generation of revenues. The term "agripreneurs" refers to business owners in the agricultural sector. Government representatives must support entrepreneurs and impart new skills that will lead to commercialization. Farmers must begin collective farming and work with government financial and technical agencies, FPOs, NGOs, and organizations. Such projects can be used to investigate larger markets. Agripreneurs also help farmers or organizations by advising them on how to employ better machinery, procedures, and tactics to boost crop revenues. An agripreneur offers flexibility in managing the company, assuming risks, and structuring the agribusiness for financial success. As women are the primary participants in all stages of agricultural production including pre-harvest, post-harvest processing, packaging, and marketing implementing gender-specific interventions is crucial to enhance agricultural productivity. Agri-startups, which introduce innovation and technology to farming, have emerged as key players. Among the driving forces behind this transformation are women entrepreneurs who are increasingly leading agri-businesses and startups focused on sustainability, inclusion, and economic empowerment. From launching tech-driven solutions for smallholder farmers to building sustainable food supply chains, women-led Agri-startups are reshaping the agricultural landscape. Empowering women in agri-startups not only promotes gender equality but also has the potential to significantly improve food security (Bano and Hasnat, 2024). However, socioeconomic barriers continue to restrict women's involvement in agripreneurship. These interventions are necessary to ensure equitable opportunities for women in India's agripreneurial ecosystem. In all commercial and agricultural production processes, women are also essential. The foundation of subsistence farming is

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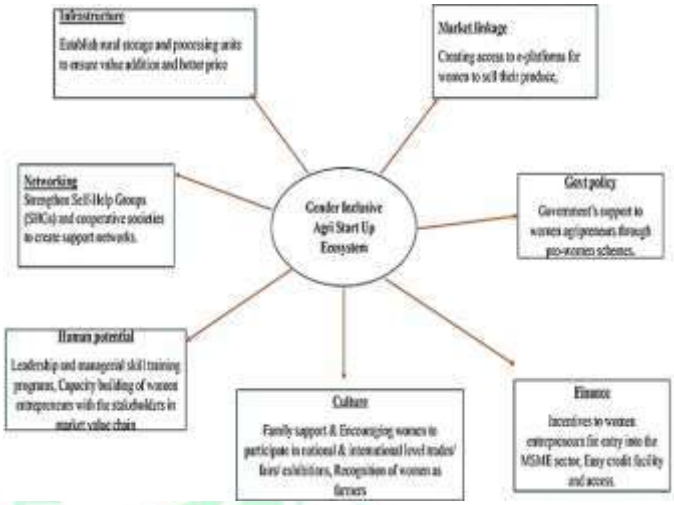
comprised of female farmers. They do not get the credit they merit in spite of this. The rights and requirements of female farmers have been totally disregarded. The circumstances facing female farmers are no better than those facing agricultural labor. In order to achieve sustainable development, women farmers must be involved in development initiatives and given fair compensation for their labor. Sanchez and Pindado (2017) According to the study, writers have connected agripreneurship to the rise in non-agricultural enterprises founded by seasoned farmers. On the other hand, a number of studies show that agribusiness ventures provide opportunities for a wide range of products and innovation in the areas of marketing, distribution, and business processes.

Agripreneurship for Women

Since women are the backbone of society, their empowerment also benefits the entire planet. Women make up almost half of farmers worldwide, and almost 70% of them are in India. On average, almost half of the world's food production is done by women. Up to 89.5% of all female workers in rural India are employed in agriculture and related industrial sectors. It is estimated that women contribute between 55% and 66% of all labor in farm output. Growing numbers of women are pursuing entrepreneurship and breaking into previously unheard-of business domains. In India as 60-65 per cent women are farmers, so it`s the best measure to empower them on their stay. This can be possible through entrepreneurship in agriculture sector which in short called as Agripreneurship. Empowerment of women through agri-preneurship will ultimately serve our purpose of gender equality so also food security.



Women- Harbingers of Change

Gone are the days when farm women would end up their entire life within the 4 walls of the house. Indian economy is basically an agrarian economy; it can serve as a platform for women empowerment through agricultural entrepreneurship, Food processing and other allied activities.

- ✓ Gender equality
- ✓ Self-reliance through self-employment.
- ✓ Bringing about equitable distribution of income and wealth.
- ✓ Enhancing income of women bringing sense of security
- ✓ Reducing poverty and improving the equality of life of farm families.

Women in any country play an important role in the nation's progress

To quote late Prime Minister of India Shri Jawaharlal Nehru "You can tell the condition of the

nation by looking at the status of its women". It follows that along with gender sensitization what is important is Women Empowerment.

Innovation in agriculture: Women-led startups are introducing Agri-tech solutions like precision farming, smart irrigation, and AI-based tools to enhance crop yields, reduce resource wastage, and increase profitability. They are using blockchain for supply chain transparency and creating digital platforms to connect farmers with buyers, reducing middlemen and increasing farm incomes (Maurya, 2024).

Value-added agriculture and food processing: Another important possibility for female entrepreneurs is value-added agriculture, which entails processing agricultural products to boost their worth. Women can increase their profitability and gain a greater portion of the agricultural value chain by working in industries like food processing, packaging, and branding. Women entrepreneurs, for instance, can transform dairy goods into cheese or yogurt or turn raw fruits into jams, preserves, or dried fruits. Women can raise their incomes because these value-added goods frequently have larger profit margins than basic agricultural commodities. Entrepreneurship is vital part of the agricultural sector, complex regulatory policy mechanisms have been ambiguous so far suggest that agriculture is a field must be studied differently from other types of economic activities (Alsos *et al*., 2020).

Sustainable farming practices: Climate-resilient crops, organic farming, and the advancement of sustainable agriculture methods are all supported by numerous female entrepreneurs. Their focus on environmental sustainability helps achieve long-term environmental objectives like lowering greenhouse gas emissions and protecting biodiversity, as well as eco-friendly farming practices that complement international green programs.

Improved supply chain management: From farm to market, women-led enterprises are optimizing processes through value chain management and logistics. Technology is being used to enhance food delivery and lower post-harvest losses.

Accessing niche markets: Targeting niche markets that are sometimes disregarded by bigger companies might also be advantageous for female agricultural entrepreneurs. These markets feature native foods with specific cultural or nutritional value, heirloom cultivars, and specialty crops. Women entrepreneurs can produce unique goods that appeal to particular consumer categories and fetch high prices by concentrating on these niche markets. Furthermore, niche markets frequently support ethical and sustainable business practices, which appeal to customers who care about the environment.

Social entrepreneurship in agriculture: A growing number of female entrepreneurs are also adopting social entrepreneurship strategies, which blend social impact with financial gain. In addition to building prosperous companies, these entrepreneurs are tackling urgent social issues by emphasizing gender equality, rural empowerment, and community development. For instance, empowering smallholder

farmers, enhancing food security, or giving rural women job opportunities are the main goals of some women-led agristartups. These programs improve entire communities by generating a positive feed-back loop of social and economic advantages.

Approaches to Empower Women in Agribusiness

Capacity building: through organizing training programmes, exposure visits, vocational trainings group discussions, involving them in national and international trade fair etc. which will help in developing their technical skills and also builds self-confidence.

Self-help groups: This approach already witnessed excellent results in many developing countries. Further it needs to be sustained and improved the performance by way of encouraging the women self-help groups have emerges as an important strategy for empowering women and alleviating poverty.

Access to Credit, Savings and Financial Services: Empowering women to use the money loaned in the way she planned.

Integrated Approaches: Given the diverse roles that women play in communities and families as well as the multiple and overlapping forms of disempowerment they face. Integrated projects tend to especially benefit women.

Conclusion

Through providing farmers with integrated farming systems, crop management, animal husbandry, dairy, and fisheries, the agriculture sector significantly contributes to the national economy. Young people, particularly women, have the chance to demonstrate their skill set in this field through specialized knowledge and technological advances that enable them to support themselves. In order to achieve sustainable growth, the agriculture sector must boost output and profitability and provide the necessary nourishment for everyone. The agriculture sector gives women entrepreneurs the chance to collaborate in order to explore a variety of uncharted territories or succeed while using contemporary methods to generate income. Women are contributing in many ways to the expansion and advancement of agriculture.

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Soil Health and Sustainability in the Age of Organic Amendments

Rajkumar D. Shinde, Papita H. Gourkhede and Madhavi Dattatrya Jangilwad

Introduction

It was predicted that food production would need to double over the next few decades in order to feed the world's continuously expanding population. In addition to the widespread use of irrigation, technology, and synthetic fertilizers, the Green Revolution brought new livestock breeds and crop kinds. Since the early 1960s, agricultural systems have produced significantly more food thanks to agrochemicals (pesticides, fertilizers). Agricultural land intensification, not expansion, was the driving force behind this global growth in food supply. Seeking for enhanced crop productivity, agricultural intensification was sustained by indiscriminate inputs of synthetic agrochemicals, an overuse of water, and the alteration of the soil ecosystem, at great expense to the environment. Indeed, replacing soil internal processes with external inputs resulted in the progressive deterioration of the fundamental properties of those soils, including the potential for self-regulation (Bender *et al*., 2016). Soil is a multi-functional, extremely complex, and highly dynamic three-dimensional system in which solid, liquid, and gaseous components interact in multiple physical, chemical, and biological processes. On the other hand, soil is a non-renewable resource at the human scale. Numerous processes and the provision of essential ecosystem services are supported by healthy soils. The ability of a particular soil to carry out its tasks is a common definition of soil health or quality. While the terms are frequently used interchangeably, soil health is usually used more broadly to refer to "the capacity of soil to function as a vital living system to sustain biological productivity, promote environmental quality, and maintain plant and animal health," while soil quality is typically associated with a soil's fitness for a particular use. The maintenance of soil health is essential for preserving biodiversity, as soils are home to a significant proportion of global biodiversity. However, there's growing concern about declining soil health due to various anthro-pogenic activities. Land degradation, including erosion, loss of organic matter, compaction, salinization, and the presence of contaminants, is jeopardizing the health and productivity of soils worldwide. The significance of this degradation is not just local or regional; its implications are global,

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particularly considering the vital role of soils in climate regulation, water availability, and food production. In response to concerns about declining soil health, there has been a renewed interest in traditional and innovative soil management practices, including the use of organic amendments. Organic amendments can be broadly defined as materials derived from living organisms, added to soils to improve their physical, chemical, and biological properties (Neina, 2019). Building soil organic matter is a central aim and outcome of organic soil health practices. Plant residues, animal manures, compost, and other carbon-based soil amendments fuel soil microbes and fauna while enhancing moisture and nutrient retention and binding properties.

Traditional Soil Management Practices

Historical civilizations have long understood the importance of fertile land for crop production, with early agricultural societies implementing various soil management practices to maintain and enhance soil fertility. From the dawn of agriculture to modern-day, soil management has evolved, adopting practices based on cultural knowledge, scientific understanding and technological advances. This section delves into traditional soil management practices, including their historical methods, the advent of synthetic fertilizers, and the implications of tilling and monoculture on soil health. Long before the introduction of synthetic inputs, early farmers utilized a myriad of practices, developed over generations, to maintain soil fertility: Crop rotation: The ancient farming communities recognized the importance of rotating crops to reduce pest pressure and enhance soil fertility. This technique entails developing distinct successive crop types on the same patch of land, which facilitates the cycle of nutrients and Reduces infections spread via dirt. Utilizing manure and compost: Historical societies such as the Indus Nile Delta and the Valley, combined cattle farming while producing crops. Waste from livestock provided a useful supply of organic matter as well as crop nutrients. The process of composting organic stuff, such as leftovers from plants and animal feces, which offers a significant supply of a variety of nutrients and organic substances, improving the structure and fertility of the soil through agroforestry. Numerous indigenous groups worldwide engaged in agroforestry, which involves incorporating trees onto agricultural lands.

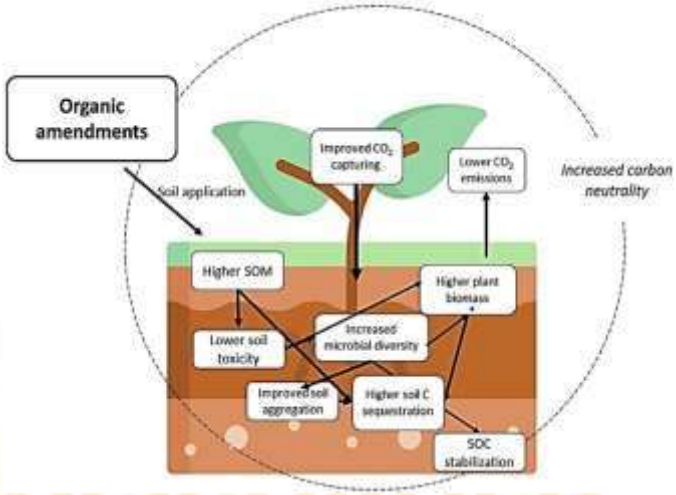
Organic Amendments: Our current production systems and transformation processes, designed to create useful goods and services, usually entail the continuous generation and disposal of massive amounts of waste. The required transition toward more ecological and sustainable production systems demands changing the current linear production model, where resources are converted into products and waste, to a circular model which, in a way, attempts to mimic the principles and functioning of natural ecological processes and cycles (Maina, 2017). Within this circular economy paradigm, the reutilization of organic waste and by-products as soil amendments is gaining much interest, since it poses

a realistic, cost-effective, and environmentally sound alternative to landfill disposal (the least preferred option for waste management). Organic amendments, such as composts, animal manures, slurries, crop residues, digestates from the anaerobic treatment of waste, bio solids, etc., are extensively applied to agricultural soil as fertilizers or, alternatively, as amendments in soil remediation and reclamation initiatives. Biofertilizers, defined as "mixtures of selected beneficial microorganisms and/or other organic substances (plant growth hormones, vitamins, etc.) for sustainable soil management and plant productivity", are broadly applied worldwide given their promising potential. Recently, biofertilization techniques" were included within the group of organic residues most commonly used as soil amendments.

Categories of organic amendments

Crop Residues and Green Manures: Green manure refers to "certain forage or crop varieties that are incorporated into the soil while green or soon after maturing," whereas crop residues are described as the "non-edible part of the plant that is left in the field after harvest". These plant-based amendments are regarded as "the greatest source of soil organic matter (SOM)" for agricultural soils and are a valuable supply of organic matter (OM). They can also prevent soil erosion, control weeds, boost soil fertility, and improve the physicochemical and biological characteristics of the soil.

Animal manures: Composed of feces, urine, and animal bedding, animal manure was long used as soil organic amendment since it can enhance soil fertility through the supply of essential macro- and micro-nutrients, as well as organic matter. The application of animal manure can improve soil structure by reducing bulk density and increasing soil porosity, water infiltration/percolation rate, and aggregate stability (Edmeades, 2003).



Biosolids: Sewage sludge, another name for biosolids, is a solid organic residue that comes from wastewater treatment facilities. Applying these organic additions to agricultural soil can have a significant positive impact on soil fertility due to the abundance of macro- and micronutrients they contain. In fact, adding biosolids to soil has been demonstrated to improve its physicochemical and biological characteristics, and it has been suggested that this is an appropriate method for sequestering carbon in agricultural soil.

Compost: The decomposition of OM under controlled aerobic conditions can lead to a stable, humus-like end product known as compost. Compost can be produced from a wide array of organic materials, including agrarian (crop residues, animal

manures) and municipal solid waste and sewage sludge. In fact, compost constitutes the most commonly used organic amendment for agricultural fertilization. By adding organic matter (OM) to agricultural soil, composted additions increase the soil's microbial activity and biomass while also enhancing its porosity, aeration, water-holding capacity, aggregate stability, and nutrient availability.

Role of Organic Amendment in Crop Yield and Quality

Organic amendments have long been associated with the restoration of soil health and the enhancement of environmental quality. However, their direct and indirect impacts on crop yield and quality are a focal point for both the scientific community and farmers. By delving into multiple dimensions of crop production, from yield quantity to nutrient quality, we can better understand the comprehensive influence of organic amendments. A complex soil food web, comprising bigger species like earthworms as well as bacteria and fungi, is typically found in organically treated soils. As organic materials decompose, this finely woven web is essential to the gradual release of nutrients. Plants are guaranteed a steady supply of nutrients throughout all stages of growth because to the constant delivery of nutrients rather than the sporadic spikes typical with synthetic fertilizers. Mycorrhizal fungus-rich organic amendments, in particular, aid in the development of symbiotic connections with plant roots. By extending their hyphae into the soil, these fungi effectively broaden the root's reach and make it easier for the plant to absorb vital nutrients like phosphorus and specific micronutrients that would otherwise be unavailable. These differences are attributed to the enhanced soil health and nutrient availability in organically managed soils. Furthermore, the taste, often subjective yet discernible, is believed to be better in organically grown produce. Although concrete scientific evidence on this is sparse, it's hypothesized that the rich microbial activity and balanced nutrient profile in organically amended soils contribute to the improved taste of crops.

Conclusion

Growing awareness of organic amendments' contribution to sustainable agriculture has highlighted their many advantages, which include better crop production, increased soil health, and less environmental impact. The potential to maximize the use of organic amendments through precision farming becomes more apparent as technological advancements blend with conventional agricultural methods. Taking advantage of opportunities like upcycling waste materials opens the door to a comprehensive strategy for sustainable agriculture. Composting and anaerobic digestion are acknowledged to be efficient for overcoming some of the potential adverse impacts that organic amendments may exert on the soil ecosystem and, in general, the environment.

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RNA Interference: A Novel Approach for Plant Disease Management

Sowmya M., Rashmi S. and Megha B.

Introduction

Since the beginning of agriculture, people have worked the land to feed their offspring, which has contributed to population expansion over time. Thousands of years later, one of the largest problems facing contemporary agriculture is how to produce food in a sustainable, efficient, and lucrative manner to feed the world's population of roughly 10 billion people by the year 2050. A number of problems, including insect damage, disease, and weed competition, have been limiting agricultural output and lowering crop yield below its potential. For example, 20-40% of crop loss is caused by insects (Oerke, 2006). Furthermore, scientists predict that in the coming years, insect damage will rise by 10 to 25% for every degree that the global temperature rises, with temperate zones experiencing the majority of the issues. Modern agriculture is now entering the third green revolution, based on the significant progress in the use of reverse genetics to elucidate gene function and applying this knowledge in pest management. Major progress was made by Fire and Mello in 1998 by elucidating the gene-silencing mechanism in eukaryotic organisms named as RNA interference (RNAi). RNA interference (RNAi) is a conserved regulatory mechanism of gene expression that has been recently characterized in plants and invertebrates. It is a homology-dependent nucleotide sequence specific process of mRNA degradation or translation inhibition at the post-transcriptional level or epigenetic modification at the transcriptional level depended on RNA-directed DNA methylation (RdDM in plants) (Duan *et al*., 2012). It refers collectively to diverse RNA based processes that result in sequence specific inhibition of gene expression at the transcriptional or translational level. Once RNAi is triggered in a certain cell, a mobile signal is produced and spread through the whole plant causing the entire plant to be silenced. RNAi has rapidly gained importance as a reverse genetics tool to knock down expression of targeted genes in plants, lower animals and micro-organisms. This technology has been widely applied to alter the gene expression in plants with an aim to achieve desirable traits. RNAi has been used for enhancing the crop yield and productivity by manipulating the gene involved in biomass production, grain yield and enhanced shelf life of fruits and vegetables and nutritional improvements of crops.

Mechanism of RNA interference

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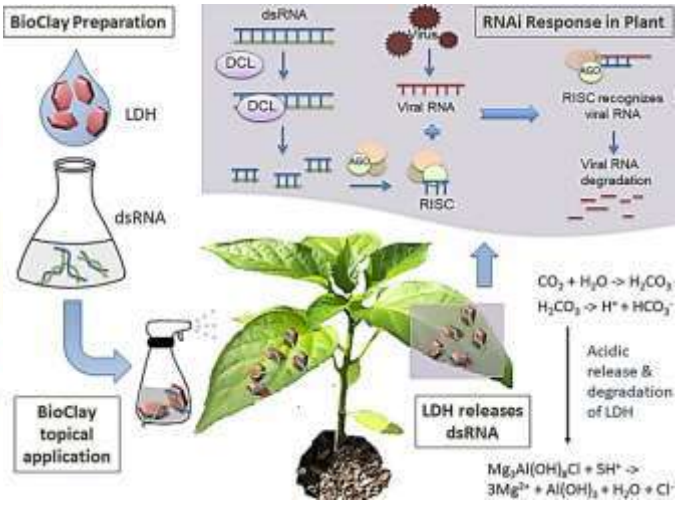
RNA silencing is triggered by ds RNA that results in silencing of specific genes before being translated in a homology dependent manner. The entry of long dsRNA such as an intro duced transgene, a rogue genetic element or a viral intruder is needed to trigger the RNA silencing. This recruits host ribonuclease -III like enzyme called Dicer with distinctive ds RNA binding, RNA helicase, RNase III and PAZ (Piwi/ Argonaute/ Zwille) domains. Dicer binds to long dsRNA and then cleaved into small interfering RNAs (si RNAs) of 21-25 nucleotides (nt) in length. Small interfering RNAs (siRNAs) medi ate the selective degradation of target RNA by guiding a multi-component RNAse, RNA-induced silencing complex (RISCs). It is a multi-complex protein consisting of a member of Argonaute (Ago) protein family. Ago protein contains two do mains: PAZ domain- siRNA binding domain and PIWI domain- that provides endonucleolytic (slicer) activity to those RISCs programmed to cleave target RNAs. RISCs distinguish the siRNA strands as either sense / antisense. Finally, RISC target homologous mRNA for cleavage and degradation of sense strand based on complementary base pairing. The antisense strands in the RISC guided to target mRNA in a sequence specific manner. The activated RISC thus participates repeatedly in mRNA degradation inhibiting protein synthesis. The Dicer-Ago core executes a diverse set of ssRNA directed biological function in higher plants.

Approaches to induce RNAi

Resistance through RNAi in plants has been achieved by expressing hp RNA that folds back to create a dsRNA *in vivo*. delivering artificial micro (mi) RNA or by directly delivering RNA silencing molecules into plant tissues.The hairpin inverse repeat sequences from viral genomes can be small hpRNA, self-complementary hpRNA, and intron-spliced hpRNA. Among these methods, self-complementary hpRNAs separated by an intron likely elicit post- transcriptional gene silencing (PTGS) with highest efficiency.



RNAi in plant disease management

RNAi technology has emerged as one of the promising strategy for enhancing resistance in plants to tackle the biotic stresses caused by fungal, bacterial, viral and nematode diseases that causes huge losses in important agricultural crops (Singh, 2005).

RNA silencing-mediated resistance to plant fungal pathogens: Most Fungal pathogen interact with their corresponding host through a highly specialized cell called a haustorium. This structure is surrounded by extra-haustorial matrix bordered by

plants and fun gal membranes on either side. Besides facilitating signal exchange and nutrient uptake, this also points to the possibility of trafficking of dsRNA or siRNA from host plants into the fungal pathogens to trigger RNA silencing mediated resistance. Gene silencing may occur in haustorial cells and could disrupt pathogenesis or other metabolic processes if silencing signals produced in the host cell are able to get across this barrier and exchange. Host-induced gene silencing (HIGS) is the term for this kind of gene silencing. According to Nowara *et al*. (2010), HIGS has been seen in the barley powdery mildew fungus Blumeria graminis. When gene fragments from the rust fungi *Puccinia striiformis* f.sp. *tritici* or *P.graminis* f.sp. *tritici* were transferred to plant cells via the Barley Stripe mosaic virus system, some decreased the expression of the corresponding genes in the rust fungus. This development of a host-induced RNAi system has also been documented in the wheat stripe rust fungus (*Puccinia striiformis* f.sp. *tritici*). This has to do with patterns of fungal gene expression. Development of host induced RNAi system has also been reported in wheat stripe rust fungus (*Puccinia striiformis* f.sp. *tritici*) where gene fragments from the rust fungi *Puccinia striiformis* f.sp. *tritici* or *P. graminis* f.sp. *tritici* were delivered to plant cells through Barley stripe mosaic virus system and some reduced the expression of the corresponding genes in the rust fungus. This is associated with fungal gene expression patterns (Yin *et al*., 2011).

RNA silencing-mediated resistance to plant pathogenic bacteria: For the first time, Escobar *et al*. (2001) reported employing RNA interference (RNAi) to develop plant resistance to the bacterial pathogen that causes crown gall disease. Tumorogensis (gall formation) in the specific disease is caused by the oncogenes iaaM and ipt, which are also necessary for the development of tumors. These oncogenes are the focus of the disease's management approach. They demonstrated that transgenic plants (*Arabidopsis thaliana* and *Lycopersicon esculentum*) with altered versions of these two bacterial genes (s) exhibited resistance to crown gall with the aid of RNA interference technology. The transgenic genes shut down the expression of iaaM and ipt oncogenes of the incoming bacterial pathogen, thereby disturbing the hormonal production and ultimately, tumourogenesis process after infection. The pathogen responsive miRNA effects the gene expression either by suppression of negative regulators or up regulation of the positive factors required for immune responses.

Conclusion

RNAi has been an incredible functional genomics tool in the past decade. This technology will remain as potential genomic tool for the next decades to come as large scale knock down lines are being developed in major crop plants. Application of RNA silencing in single cell organisms like *Chlamydomonas reinhardtii*, an algae close to plants, will enable high-throughput plant gene function identification (e.g. for abiotic stress tolerance). A stress specific cDNA library cloned in a vector that

can induce gene silencing (e.g. sense strand over expression to induce RNAi) could be a potential source for developing knock down *Chlamydomonas* lines for each gene. By implementing high-throughput stress screening in such gene silenced *Chlamydomonas*. If RNAi technology is devel oped successfully and employed for management of major diseases on commercial scale, they can prove to be an eco-friendly and biologically safe technology. Moreover, this technique eliminates the risk associated with development of transgenic and it will also gener ate enormous potential for engineering control of gene expression.

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Recent Advances in Biological Control

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Introduction

Biological control can defined as the use of living organisms to suppress pest populations, remains a central pillar of integrated pest management (IPM), with deep roots in pre-modern agriculture and extensive validation across decades of empirical research. The global concern over pesticide resistance, environmental contamination, and biodiversity decline has accelerated research into next-generation biocontrol agents and systemic approaches. Recent progress features novel technologies, improved microbial formulations, precision agriculture, genomic tools, and a systems-level One Health perspective.

Technological Innovations in Mass Production and Application

Microbial Pesticides and Formulation Advances

Recent work has established high-efficacy microbial biopesticides, such as *Trichoderma* and *Bacillus* species, with advanced mechanisms of antagonism, mycoparasitism, antibiosis, induced systemic resistance (ISR), and lipopeptide production (Sun *et al.*, 2021). Innovations such as layer-by-layer encapsulation, biopolymer-based emulsions and cell-cap encapsulation have improved agent stability, viability, and effective delivery.

- ✓ Genetic enhancement and CRISPR-based modification have increased microbial metabolic activity and target specificity, generating strains with superior pathogen suppression.
- ✓ Commercial advancements include recombinant DNA applications, such as Mycogen CellCap® encapsulation, to deliver fragile biopesticide molecules to the field environment (Pitterna *et al.*, 2009).

Precision Agriculture and Data-Driven Deployment

The integration of real-time pest population monitoring and predictive analytics has enabled targeted biocontrol applications, optimizing field outcomes and reducing environmental impact. Sensors, remote-sensing platforms, and algorithmic threshold models inform the timing, location, and dosage of biological agents, revolutionizing pest management strategies.

Genetic and Molecular Tools

Genomic Understanding and RNA Interference (RNAi)

Genomic tools have illuminated host-pathogen interactions and signaling pathways critical

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to advancing biocontrol efficacy (Hubbard *et al.*, 2020). RNA interference is now deployed to silence critical pest genes, either directly or via symbiotic microbes, yielding species-specific suppression with minimal off-target effects.

- ✓ Transgenic crops expressing *Bacillus thuringiensis cry* genes confer resistance to insect pests, reducing the need for chemical interventions.
- ✓ Synthetic symbionts and engineered gut microbiomes emerge as next-generation solutions for pest suppression with enhanced stability and environmental safety.

Sterile Insect Technique (SIT) Upgraded for Screwworm Control

USDA researchers at the Knipling-Bushland lab near Kerrville, Texas, are modernizing the classic sterile insect technique (SIT) to combat the New World screwworm fly (U.S. Department of Agriculture, 2025) Innovations include:

- ✓ More selective attractants and traps aimed at capturing only females**,** while preserving sterile males for population suppression.
- ✓ Genomic surveillance that tracks origins of outbreak strains, like connection of Florida cases to populations in the Dominican Republic and Trinidad and Tobago, informing better containment strategies.

RNA Pesticides: Precision against Varroa Mites

GreenLight Biosciences is advancing an "RNA pesticide" designed to target genes unique to the destructive varroa mite: without harming bees or other beneficial species. Delivered *via* sugar syrup given to worker bees, this technique interrupts mite development at the molecular level. It has shown promise in lab settings and reflects a growing trend toward highly specific, eco-friendly control measures.

Tiny Wasps as Eco-Friendly Moth Guards

Rentokil has begun using entosite parasitoid wasps, tiny insects less than half a millimeter in size: to control moth infestations in museums, historic homes, and other spaces with delicate textiles. The wasps lay their eggs inside moth eggs, stopping larvae from hatching. This non-toxic strategy offers continuous protection without harming fragile artifacts and aligns with successful past uses of parasitoids in agriculture.

Drone-Assisted Biocontrol: UAV-IQ's Aerial Releases

Agritech startup UAV-IQ is leveraging drones to deploy beneficial insects, like predatory mites and parasitoids over crops with unprecedented precision. Their drone system supports targeted releases in vineyards, offering:

- ✓ Efficient coverage over fields.
- ✓ Reduced labour costs.
- ✓ Better integration with existing Integrated Pest Management (IPM) practices. One key project, funded by the California Department of Food and Agriculture, focuses on controlling vine mealybugs using predators (*Cryptolaemus montrouzieri*) and parasitoids (*Anagyrus pseudococci*) *via* drone delivery.

Microbial Consortia & Biopesticides: Fighter Teams against Nematodes

A 2025 review highlights a surge in research using bacteria and fungi, alone or as microbial consortia, to suppress phytoparasitic nematodes. These blends offer multiple modes of action and more reliable persistence than single-strain agents. Although still emerging in commercialization, they hold promise for sustainable, broad-spectrum nematode control.

Biopesticides & RNAi: Targeted Molecular Attacks

- ✓ Microbial biopesticides, using bacteria, fungi, or viruses, are becoming more potent and refined, offering targeted pest suppression with minimal non-target impact.
- ✓ RNA interference (RNAi) technologies allow silencing of pest-specific genes. The first such U.S.-approved insecticide, Calantha, targets a critical gene in the Colorado potato beetle.
- ✓ Advances such as encapsulating dsRNA in nanoparticles improve stability and field efficacy of RNAi-based solutions.

Smart Tech & Biocontrol: AI, IoT, and Policy Drivers

Emerging technologies, including AI, real-time sensors, and the Internet of Things, are enabling smarter monitoring and deployment of biocontrol agents. Reinforced by evolving policies that favor non-chemical pest management, these innovations are accelerating adoption of advanced biocontrol worldwide.

Summary Table: Advances at a Glance

Innovation	Key Advantage
Modernized SIT (screwworm)	Genomic surveillance + improved female-specific trapping
RNA pesticides (varroa mite)	Species-specific targeting via feeding behavior
Parasitoid wasps	Non-toxic, continuous moth control for delicate environments
Drone-based insect releases	Precise, labor-efficient deployment in agriculture
Microbial consortia	Enhanced efficacy & resilience vs. single agents
RNAi & microbial biopesticides	Eco-friendly, accurate molecular pest disruption
AI/IoT + supportive policy	Data-driven deployment + favorable regulatory environment

Ecological Approaches and Systems Integration

Conservation Biological Control

Conservation biological control leverages habitat manipulation, such as flowering strips, hedgerows, and reduced pesticide use, to support beneficial arthropods and sustain ecosystem services. Studies demonstrate resilient pest suppression and biodiversity enhance-ment through these landscape-scale interventions.

One Health Contributions

A One Health perspective connects biolo-gical control to human, animal, plant, and environmental health, mitigating risks from chemical pollution, biocide resistance, and biodiversity loss (Schaffner *et al.*, 2024). Biological control has controlled at least 15 weed and 12 insect species in natural habitats, supporting restoration and ecosystem resilience.

Notable cases: Biocontrol of cassava mealybug in Asia reduced tropical deforestation; fungal control of locusts decreased aerial insecticide use, enhancing multi-sectoral health outcomes.

Mechanisms of Action

Recent reviews clarify the biological and chemical interactions underlying successful control. *Trichoderma* species employ mycoparasitism and antibiosis, while *Bacillus* species utilize lipopeptides and siderophores, directly inhibiting pathogen growth (Ferreira Filho *et al.*, 2020). Application of surfactants such as Silwet L-77 increases microbial penetration into plant tissues, improving efficacy (Johnson *et al.*, 1996)

Regulatory and Commercial Trends

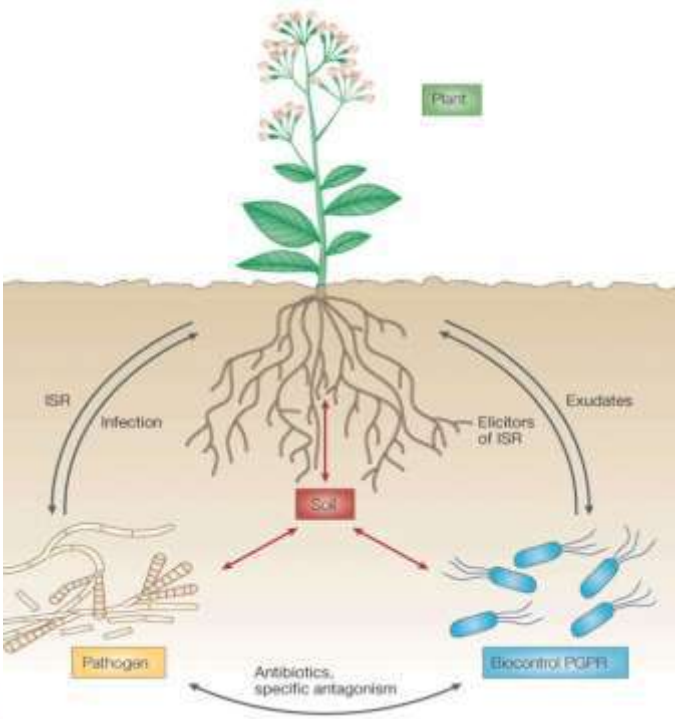
Formulation stability, commercial viability, and regulatory approval remain central challenges (Muras *et al.*, 2021). Layer-by-layer encapsulation and polymeric emulsions have increased shelf-life (Løvschall *et al.*, 2024), while genetic enhancement strategies like mutagenesis, recombinant gene integration, drive agent potency and specificity.

- ✓ Regulatory harmonization across borders is essential for global deployment of biocontrol products.
- ✓ Societal awareness of food safety and environmental sustainability promotes biocontrol adoption.

Future Directions and Research Priorities

Multidisciplinary Collaboration

Recent studies advocate integrated approaches that transcend disciplinary boundaries, leveraging plant pathology, entomology, molecular biology, and ecology. Cooperation among scientists, practitioners, and policymakers aims to realize the full public health and environmental potential of biological control.



Sustainability and Resilience

Future research will focus on:

- ✓ Further optimizing genetic tools for biocontrol agent improvement.
- ✓ Harnessing ecological intelligence for landscape-level resilience.
- ✓ Enhancing data-driven deployment for cost-effective application.
- ✓ Evaluating long-term ecosystem effects and non-target safety.

Conclusion

Biological control stands at a frontier of sustainable agriculture and ecosystem management. Recent advances in microbial agents, genetic engineering, precision agriculture, and ecological integration demonstrate both scientific innovation and real-world relevance. The One Health framework underscores its multifaceted benefits, and continued interdisciplinary collaboration will ensure

biological control remains pivotal amidst future agricultural and environmental challenges.

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Ecological Role of Spiders in Terrestrial Ecosystem

Surendra Prasad, Viresh Sadashiv Jeur and Patne Yashwant Babarao

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 knowledge 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 are members of the class Arachnida, and order Araneae. The biggest order of arachnids, spiders are ranked seventh among all other groupings of organisms in terms of overall species diversity. Spiders are amazing animals; the fossil record shows that they first appeared as living things 380 million years ago, during the Devonian period. Their body is divided into two segments cephalothorax and abdomen; the former has four pairs of segmented appendages, is wingless, and lacks chewing mouth parts. Spiders were recognized by their distinctive ability to produce silk thread. Although many spiders are incapable of spinning webs, all spiders are capable of producing silk thread, which they employ to form sacs to hold eggs, build nests, and, most often, wrap prey. The overreliance on insecticides in agriculture has led to adverse effects like species extinction, resistance development and environmental pollution. Integrated Pest Management (IPM) strategies, incorporating non-chemical control methods alongside insecticides, have emerged as solutions. Utilizing natural enemies like predatory insects in IPM systems has shown promise, benefiting both perennial horticulture and field crops. Effective biological control requires predators to not only reduce pest densities but also stabilize them over time. Spiders, as obligate predators, hold promise in meeting these requirements. Different spider families target various pest groups through diverse hunting strategies. For instance, orb-web weavers like Araneidae and Tetragnathidae target leafhoppers and Diptera, while sheet-web weavers such as Linyphiidae and Theridiidae capture aphids and leafhoppers. Despite their potential, spiders have often been overlooked as

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Table 1: Classification of predatory spiders based on foraging style

Group	Families	Species
Tarantulas	Theraphosidae	*Aphonopelma chalcodes* (typical tarantulas)
Primitive hunters and weavers	Scytodidae	*Scytodes* sp. (spitting spiders)
Small hunters	Thomisidae	*Mmisumenops asperatus* (crab spiders)
	Salticidae	*Metacyrba* sp. (jumping spiders)
Large hunters	Pisauridae	*Dolomedes tenebrosus* (nursery web spiders)
	Lyco sidae	*Lycosa ceratiola* (wolf spiders)
	Sparassidae	*Heteropoda venatoria* (giant grab spiders)
Web weavers	Filistatidae	*Filistata hibernalis* (snare weavers)
	Araneidae	*Argiope aurantia* (orb weavers)
	Agelenidae	*Agelenopsis pennsyvanica* (funnel web weavers

biological control agents due to a limited understanding of their ecological role. Spiders are abundant in both natural and cultivated environments, in which their average annual abundance ranges from 50 to 150 individuals per square meter but can periodically reach maximal densities of more than 1000 individuals per square meter (Pearse, 1946). They are considered to constitute one of the dominant macroinvertebrate predator groups in terrestrial environments (35-95%). Spiders are exceedingly interesting subjects for study, for some of the most remarkable exhibitions of intensive powers presented by them. The spider has hit upon the device of turning its food into silk and using it as a trap to catch more food. Spiders feed on insect pests and kill as much as 100 times the number of prey they actually consume and thus operating a good natural control of insect pests. Each year, they consume over 400-800 million tons of prey, largely insects. Year (roughly the whole human mass on the world), managing bug populations that could otherwise destroy the crops (Nyffeler and Birkhofer, 2017). Spiders also various predators and parasitoids, including birds, amphibians, lizards, snakes, shrews, mice, bats, and fish, rely on them for sustenance.

Morphological characters (Tikader, 1982)

The body of the Spider divisible in to a distinctive cephalothorax and abdomen, joined together by a narrow pedicel. The cephalothorax is covered dorsally by a hard sclorotic shield the carapace, and ventrally by sternum. The anterior articulates movably with the labium. The legs are articulates in the plural membrane between the lateral edges of the carapace and sturnum. On the cephalic region are present six to eight eyes. The eyes are generally of two kinds, viz, black or diurnal and white or nocturnal eyes. When only one type is present, the condition is described as homogenous, in contrast to heterogeneous, when both the type are present. The eyes are usually arranged in double row, viz, the anterior row and posterior row. Each row usually contains four eyes. The chelicerae are preoral structures located below the clypeus and are either porrect (if projected forward) or geniculate (if the proximal base is stout and they are directed forward for a distance before the main portion bends down vertically), and are used in the capture and killing of prey, courtship and mating display, and also in defense.

Life history of spiders

Spiders reproduce sexually. Sexual dimorphism is also distinctive. Male spiders are usually smaller than female spiders. In some species, such as the Giant Wood Spider, females can be 3-5 times larger than males. Mature males can be differentiated from females by their larger bulb-like palps, which store sperms. The female lays up to 3,000 eggs, which are normally encased in an egg sac, silk cocoon, or egg nest. Cocoon shapes vary per species, including round, spherical, fusiform, and bell-shaped. Cocoons are often camouflaged with plant or soil particles to blend in. Eggs hatch after a span of 20-30 days. The young spiderlings leave the egg chamber and stay sedentarily in the more spacious moulting chamber for about 7-15 days. A few days after first moult inside the chamber, the most agile spiderlings cut a circular opening into the cocoon wall and in a few minutes the spiderlings crawl out of the cocoon one after another. Approximately 100-300 spiderlings remain on the mother Iycosid's back for 5-8 days before dispersal, relying solely on the reserve yolk supply. Spiderlings consume 'water' from the mother spider by eating the cocoon held by the chelicerae. During a packed journey, several spiderlings fall and must live on their own. Spiders' life histories vary depending on their species. Smaller species require fewer moults, while larger species typically have longer developmental periods to reach sexual maturity.

Spiders as Bio indicators: Spiders are well documented as potential bioindicator in various ecosystems and their role in the dynamics of insect pest population controlled is well known, therefore Spiders can be used in designing future Biological Monitoring Program (BMP). Biological indicators are crucial for estimating the ecological value of natural biotopes and tracking the impact of human activities on faunistical variety and functioning. Ecosystems. This prompted researchers to investigate the other taxa may provide additional information. Typical examples include vascular plants and birds. Among Insects and arthropods are widely recognized as highly ecologically important organisms. Thus, many ecological studies on habitat conservation and on bioevaluation of human disturbances (this issue) rely on entomological data. Like insects, spiders are also present in high densities in all terrestrial biotopes, and their potential ability as bio indicators has been confirmed in many instances. Spiders are cosmopolitan in distribution except for Antarctica and have become established in nearly every terrestrial habitat. All spiders are predators and are known to be sensitive bioindicators of environmental change caused naturally or due to anthropogenic stress (Rutkowski *et al*., 2018; Stojanowska *et al*., 2020).

Spider as Predator: Spiders have potential as biocontrol agents due to their natural predatory instincts and effective hunting capabilities. Their adaptations, such as low energy maintenance and fat storage capacity, help them survive in many conditions. Individual upbringing and feeding procedures can overcome cannibalistic inclinations

and facilitate bulk replication. Spiders have long lifespans (varying from 1 to 18 years) and can survive food deprivation. Spiders have functional and numerical reactions to prey densities, reducing and stabilizing pest populations in agroecosystems. Research has shown their ability to significantly decrease pest densities across various crops. For example, spiders in maize fields have been observed to control populations of leafhoppers, thrips, and aphids. Both web-weaving and hunting spiders play crucial roles in limiting populations of phytophagous insects in different agricultural environments. Common spider families found in agroecosystems include Sac Spiders, Wolf Spiders, Lynx Spiders, Jumping Spiders, and Crab Spiders, as well as various web-weaving species. Spiders are effective predators of pest insects, promoting sustainable pest management strategies in agriculture. In rice fields, species like the Wolf spider (Lycosidae family), Jumping spider (Salticidae family), Sac spider (Clubionidae family), Lynx spider (Oxyopidae family), Crab spider (Thomisidae family), Four-jawed spider (Tetragnathidae family), and Orb spider (Araneidae family) are prevalent. These spiders inhabit various microhabitats such as lower parts of leaves, stems, water surfaces, and webs, targeting pests like brown planthoppers (BPH), white-backed planthoppers (WBPH), leaf folders, green leaf-hoppers (GLH), and mirid bugs. Erigone atra from the Linyphiidae family dominates wheat fields, devouring a variety of pests including Collembola, Diptera, Hymenoptera, Coleoptera, and Aphididae.

Spiders can colonize fields early, graze on alternate species until pest populations arrive, and attack pests before they reach peak concentrations. Their low metabolic rate allows them to live throughout periods of hunger. Throughout the world, diversity, habitat use and prey preferences by spiders in the rice agroecosystem has been extensively investigated by number of authors indicating role of spiders in Integrated Pest Management to control insect pests (Tahir *et al*., 2009).

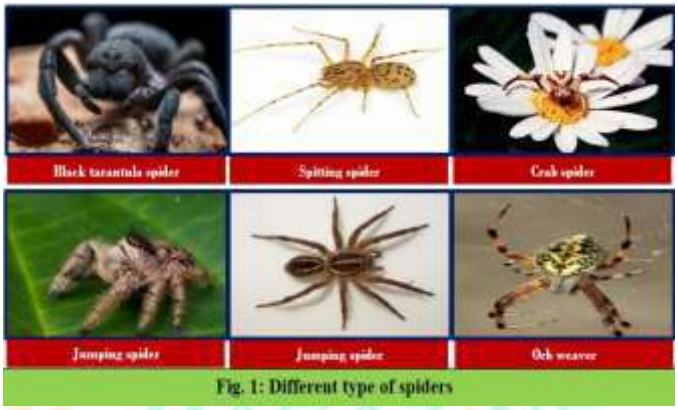

Fig. 1: Different type of spiders

Fig. 2: Predation activity of spiders

Conclusion

Spiders are members of the phylum Arthropoda, the largest phylum of animal groups in the world under the class Arachnida. Spiders are ubiquitous in distribution, invade almost every type of habitat, and are the most abundant invertebrate predators in terrestrial ecosystems. Nearly 47,617 species of spiders under 4,092 genera in 114 families were recorded in the world. Spiders are a key component of terrestrial ecosystems, occupying a

unique position in food webs. As predators, they are important in the regulation of invertebrate populations, which include pest species, and as prey, they provide food for other invertebrates and birds. The predatory spiders are divided into five broad categories depending on their feeding habits. Prey hunting ability, vast host range, case of proliferation, and polyphagous character make them a promising predator in biological pest control. The species abundance of spider communities in agricultural and horticultural ecosystems can be comparable to that of undisturbed natural ecosystems.

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Predatory Mites: Nature's Pest Control Warrior

Surendra Prasad, Neeli Priyanka and Biplab Kumar Das

Introduction

Within the framework of integrated pest management (IPM), predatory mites belonging primarily to the family Phytoseiidae have emerged as indispensable biological control agents in both protected environments such as greenhouses and open-field horticultural systems. These mites possess unique biological and ecological traits that make them highly effective in managing pest populations while minimizing the negative impacts associated with excessive pesticide use. Their high degree of prey specificity allows them to target economically important phytophagous mites and small insect pests, leading to sustainable suppression of these harmful populations. Notably, the ability of Phytoseiidae mites to rapidly establish and expand their populations in diverse agricultural habitats enhances their value in biological control programs worldwide. This adaptability is underpinned by their capacity to exploit a range of food sources, including alternative prey, pollen, and honeydew, which supports their survival and reproductive success even when target pest densities are low. Consequently, their deployment contributes significantly to decreasing the reliance on synthetic chemical pesticides, thus alleviating both ecological and human health risks linked to chemical exposures. The widespread application of predatory Phyto-seiidae mites reflects a growing recognition of their role in promoting environmentally sound pest management strategies. These mites effectively reduce pest populations such as spider mites, thrips, and whiteflies, which cause substantial damage to a variety of crop species. Their integration into IPM programs offers a durable and eco-friendly alternative to chemical treatments, aligning with global efforts to foster sustainable agriculture. Furthermore, the use of these natural enemies supports biodiversity conservation within agro-ecosystems by preserving beneficial arthropod communities and reducing pesticide-induced disruptions. Management practices that enhance the establishment and activity of predatory mites, such as habitat diversification and selective pesticide use, further amplify their impact. Collectively, these attributes render Phytoseiidae mites central to the advancement of pest control approaches that prioritize ecosystem health, economic viability, and food safety. The strategic incorporation of Phytoseiidae predatory mites within IPM frameworks exemplifies how biological control

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Table 1: Key Predatory Mite Species

Species	Pest Targets	Notable Features
Amblyseius swirskii	Thrips, Whiteflies, Broad mites, Spider mites	High efficacy, adaptable to diverse crops and climates; controls multiple pest types
Neoseiulus cucumeris	Thrips, Broad mites, Spider mites	Effective at lower temperatures; good for thrips and mite control in cooler environments
Amblydromalus limonicus	Thrips, Whiteflies, Spider mites, Broad mites	High reproductive rate; tolerates cooler climates; controls a variety of pests
Transeius montdorensis	Thrips, Whiteflies, Spider mites	Broad-spectrum predation; suited to subtropical conditions
Phytoseiulus persimilis	Spider mites (Two-spotted spider mite primarily)	Specialist predator of spider mites; historical success in classical biological control

agents can be harnessed to achieve effective pest regulation. Their biological characteristics, including rapid reproduction, environmental adaptability, and prey specificity, combined with the minimized ecological footprint of their use, position them as key contributors to sustainable horticultural production systems. By reducing the demand for chemical interventions, these mites not only enhance pest management efficacy but also foster healthier agroecosystems, supporting the resilience and productivity of agricultural landscapes globally (McMurtry *et al.,* 2013; Tixier *et al.,* 2018; Gerson and Weintraub, 2007).

Taxonomy and Diversity of Predatory Mites

Predatory mites utilized in agriculture chiefly belong to the families Phytoseiidae, Laelapidae, and Macrochelidae. The genus *Phytoseiulus*, *Amblyseius* (now syn. *Neoseiulus*), and *Amblydromalus* represent significant advances in arthropod pest suppression, with over 30 commercially available species distributed globally (van Lenteren *et al.,* 2020). These mites exhibit wide prey ranges, including spider mites, thrips, and whiteflies, but often retain an innate capacity for selective feeding dynamics that enhances their compatibility with targeted IPM strategies.

Mechanisms of Action

Predatory mites deploy a variety of sophisticated feeding and hunting strategies, shaped by evolutionary pressures within the phylloplane and soil microhabitats. Their primary mechanisms of pest suppression include:

Direct predation: Mites pierce, immobilize, and consume pest eggs, larvae, or adults, causing physical and physiological exhaustion of pest populations (Messelink *et al.,* 2008).

Population growth and persistence: Rapid reproductive cycles and the ability to utilize alternative food (pollen, nematodes) ensure predatory mite persistence even when pest densities are low, leading to long-term suppression (Navarro-Campos *et al.,* 2016).

Disruption of pest behavior: By actively hunting and feeding, predatory mites create an environment hostile to pest proliferation, thereby deterring infestation and outbreak recurrence (McMurtry *et al.*, 2015).

Ecological Integration and Crop Protection

Predatory mites can be mass-reared and applied as augmentative or inoculative releases, providing cost-effective and persistent crop protection. Soil-inhabiting taxa, though less used commercially, are gaining research attention for their ability to suppress difficult pests with edaphic life stages (Berndt *et al*., 2004). Habitat manipulation, such as mulching or intercropping, has been shown to support predator persistence and pest suppression (Muñoz-Cárdenas *et al.*, 2017; Tixier *et al.*, 2018).

Commercial Impact and Success Stories

A notable example of commercial success is the global deployment of *Amblyseius swirskii*, which has demonstrated sustained control over thrips and whiteflies in greenhouse crops (Calvo *et al.*, 2015). The mass introduction of *Phytoseiulus persimilis* in the 1960s revolutionized two-spotted spider mite management and remains a gold standard of classical biological control implementation (Gerson and Weintraub, 2007). The most effective predatory mite species for controlling both thrips and whiteflies are *Amblyseius swirskii*, *Neoseiulus cucumeris*, *Amblydromalus limonicus* and *Transeius montdorensis*. Among these, *Amblyseius swirskii* is widely recognized and commercially used because it targets both pests efficiently and adapts well to various climates and crop systems, often providing up to 98-99% suppression rates in greenhouse and field studies.

Contemporary Challenges and Research Needs

Predatory mite efficacy is modulated by numerous environmental factors, including temperature, humidity, host plant architecture, and prey availability. Key areas for future research include:

- ✓ Improved compatibility between soil and foliage-dwelling predators.
- ✓ Alternative food sources for persistence during pest scarcity.
- ✓ Soil structure and crop system adjustments for maximized predator establishment.
- ✓ Genetic and behavioral studies to understand predator-prey-plant interactions in fluctuating environments.

Sustainability and Future Outlook

Predatory mites exemplify the paradigm shift toward sustainable agriculture, consistently reducing chemical input, limiting pest resistance development, and supporting ecosystem biodiversity (Walter and Stirling, 2018). Commercial and regulatory trends continue to favor wider adoption, particularly as advances in mass-rearing, species selection, and environmental supplementation (e.g., pollen, mulching) further optimize their utility.

Conclusion

Predatory mites stand at the forefront of modern biological control. Their ability to adapt, thrive, and protect crops with minimal ecological impact validates their reputation as “nature’s pest

control warriors." Ongoing research and innovation in augmentation, habitat management, and ecological compatibility will continue to advance their central role in sustainable food production and integrated pest management.

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Utilizing Wild Relatives through Hybridization in *Brassica* Crops

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Abstract

Hybridization between individuals belonging to different species within the same genus or to entirely different genera is referred to as distant hybridization. In such cases, the parents involved are taxonomically more distantly related than varieties within a single species. This approach has been widely used in crop improvement as an effective means of transferring desirable genes such as disease resistance, stress tolerance, and quality traits from related species or genera into cultivated crops. Distant hybridization is broadly classified into two types: interspecific hybridization and intergeneric hybridization. Crossing between two different species of the same genus is known as interspecific hybridization, whereas crosses between species belonging to different genera are termed intergeneric hybridization. Interspecific hybridization plays a significant role in plant breeding and agricultural production. It enhances the genetic base of crops by enriching the gene pool and, in some cases, leads to the development of new polyploid species. In nature, such hybridization events may result in the formation of new species or facilitate the transfer (introgression) of adaptive traits across species boundaries. In agriculture, this process can be strategically utilized to achieve targeted crop improvement. Within the *Brassica* genus, interspecific hybridization has been particularly important due to the close genetic relationships among species. For example, *Brassica napus* is an amphidiploid species derived from natural hybridization between *Brassica rapa* and *Brassica oleracea*. Similarly, species such as *Brassica juncea*, *Brassica carinata*, and *Brassica nigra* share common genomes. The presence of closely related species and numerous wild relatives within the Brassiceae tribe, many of which can readily hybridize with cultivated forms, makes *Brassica* an excellent model for exploiting interspecific hybridization in crop improvement.

Brassica Crop Species and their Wild Relatives

The *Brassica* genus belongs to the tribe Brassiceae within the family *Brassicaceae*, a large plant family comprising about 338 genera and over 3,700 species. Members of this family are predominantly herbaceous plants with annual, biennial, or perennial growth habits. *Brassica* is one of the most economically important genera in this family and includes nearly 39 species, many of which are cultivated for edible roots, leaves, stems, buds, flowers, condiments (mustard) and oilseeds.

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Chromosome numbers have been determined for most *Brassica* species, ranging from n = 7 to n = 20. Three diploid species *Brassica rapa* (AA, n = 10), *Brassica nigra* (BB, n = 8), and *Brassica oleracea* (CC, n = 9) serve as the progenitors of three important allopolyploid species: *Brassica juncea* (AABB, n = 18), *Brassica napus* (AACC, n = 19), and *Brassica carinata* (BBCC, n = 17). This genomic relationship is classically described by the concept known as U's Triangle. Among these species, distant hybridization may occur both naturally and through artificial means. A well-known example is *Brassica napus*, which originated from interspecific hybridization between *B. rapa* and *B. oleracea*, followed by spontaneous chromosome doubling, resulting in a stable amphidiploid species.

Fig. 1: U triangle of origin of crop Brassicas

Applications of Distant Hybridization in *Brassica* Crop Improvement: Wild species and related genetic resources serve as valuable reservoirs of desirable genes for improving *Brassica* crops. Distant (wide) hybridization is an effective approach to transfer such useful traits from wild relatives into cultivated species. Thus, the role of wild germplasm and distant hybridization is closely interconnected in crop improvement programs. Distant hybridization has contributed significantly to the improvement of *Brassica* crops in the following areas:

Disease Resistance: Distant hybridization has been widely used to introduce resistance against major diseases from wild or related species into cultivated *Brassica* crops.

- ✓ Resistance to blackleg disease (*Leptosphaeria maculans*) has been transferred using the B-genome from species like *Brassica juncea* and *Brassica carinata* into *Brassica napus*.
- ✓ Powdery mildew resistance (*Erysiphe polygoni*) has been introduced through crosses involving *B. carinata* and *Brassica oleracea*.
- ✓ Resistance to black rot and Alternaria blight (*Alternaria brassicae*) has been transferred from species such as *Sinapis alba* and *Brassica hirta* into cultivated mustard.

Techniques like embryo rescue and back-crossing have facilitated the successful introgression of these resistance traits.

Improvement in Oil Quality Traits: Distant hybridization has been effectively used to enhance oil quality in *Brassica* crops:

- ✓ Low erucic acid and low glucosinolate traits in Brassica napus have been derived from improved cultivars such as "Liho" and "Bronowski."
- ✓ Wild relatives like *Capsella bursa-pastoris* have been identified as sources of superior oil quality traits and disease resistance.
- ✓ *Orychophragmus violaceus* has also contributed beneficial fatty acid profiles through interspecific hybridization.

Yellow-Seededness: Yellow seed color is a desirable trait associated with:

- ✓ Lower fiber content
- ✓ Higher oil and protein content

Although present in *Brassica rapa* and *Brassica juncea*, it is absent in *Brassica napus*.

Interspecific hybridization involving species such as *B. rapa*, *B. carinata*, and *B. alboglabra* has been used to transfer this trait into *B. napus*, although inheritance is complex and governed by multiple genes.

Modification of Mode of Reproduction (Male Sterility)

Distant hybridization has been instrumental in developing cytoplasmic male sterility (CMS) systems, which are essential for hybrid seed production.

- ✓ The widely used Ogura CMS system originated from crosses between *Brassica napus* and *Raphanus sativus*.
- ✓ CMS systems have also been developed using cytoplasm from species like *Brassica fruticulosa* and *Sinapis arvensis*.

Advanced techniques such as protoplast fusion and somatic hybridization have further enabled the transfer of CMS traits and disease resistance (e.g., Turnip mosaic virus resistance).

Other Agronomic Traits

Distant hybridization has contributed to several important agronomic improvements:

- ✓ C_3-C_4 intermediate photosynthesis from *Moricandia arvensis* introgressed into *B. napus*
- ✓ Dwarfism (lodging resistance) transferred from mutant *Brassica rapa*
- ✓ Pod shatter resistance introduced from *B. juncea* into *B. napus*
- ✓ Drought tolerance introgressed from *Sinapis alba*

These traits improve crop adaptability and productivity under diverse environmental conditions.

Development of Novel Genotypes: Distant hybridization can generate entirely new genetic combinations:

- ✓ *Raphano brassica*, an intergeneric hybrid between *Raphanus sativus* and *Brassica oleracea*, is a classic example.
- ✓ Artificial synthesis of species such as *Brassica amarifolia* and resynthesis of *Brassica juncea* demonstrate the creation of new, useful genotypes through amphidiploidy.

Development of Commercial Hybrids

Distant hybridization has facilitated the development of improved hybrid cultivars:

- ✓ Interspecific hybrids such as *B. napus* × *B. rapa* exhibit desirable agronomic traits and are being explored for commercial cultivation.
- ✓ CMS-based hybrid systems have enhanced hybrid seed production efficiency in crops like *B. juncea*.

Resynthesis of *Brassica* Allotetraploids

Distant hybridization can lead to:

- ✓ Introgression (transfer of specific genes)
- ✓ Speciation (formation of new species)

Resynthesis involves recreating existing polyploid species from their diploid progenitors to

enhance genetic diversity.

- ✓ *Brassica napus* can be resynthesized from *B. rapa* and *B. oleracea*.
- ✓ *Brassica juncea* has been recreated using *B. rapa* and *B. nigra*.
- ✓ *Brassica carinata* has also been resynthesized from its progenitors.

These synthetic lines are not typically released directly as varieties but are valuable sources of genetic variability for breeding programs.

Conclusion

Distant hybridization is a powerful tool in *Brassica* crop improvement, enabling the transfer of beneficial traits, development of hybrids, and expansion of genetic diversity. Its integration with modern techniques such as molecular breeding and biotechnology continues to enhance its effectiveness in developing resilient and high-yielding crop varieties.

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