



E-ISSN: 2583-1755

The Agriculture Magazine

VOLUME-5, ISSUE-8

MARCH 2026

A Monthly Peer Reviewed Magazine for Agriculture and Allied Sciences

<https://theagricultureonline.com/>



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Volume 5, Issue 8, March 2026

Monthly
ISSN: 2583-1755

The Agriculture Magazine

A Monthly Peer Reviewed Magazine for Agriculture and Allied Sciences

<https://theagricultureonline.com/>

Published by:
The Agriculture Publication



18, Keshav Nagar-1, Near Rajasthan Girls College,
Murlipura Scheme, Jaipur-302039
E-mail: info@theagricultureonline.com
Website: theagricultureonline.com

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ISSN: 2583-1755

Volume : 5, Issue : 8

March, 2026

Publication Schedule : Monthly

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The Agriculture Magazine

Volume 5, Issue 8, March 2026

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Climate-Resilient Agriculture: Enhancing Maize Productivity under Changing Climatic Scenarios

Shashi Bhushan

Introduction

Agriculture today stands at a critical cross-roads. With the growing impact of climate change, farmers across the world are facing increasing uncertainty in crop production. Unpredictable rainfall, rising temperatures, frequent droughts, and extreme weather events are no longer occasional challenges but recurring realities. These changes are not only affecting crop yields but also putting immense pressure on farmers' livelihoods, especially in developing countries like India, where agriculture remains highly climate-dependent. Traditional farming systems, though essential, are struggling to cope with these challenges. Rising input costs, declining soil fertility and unstable market conditions further aggravate the situation. In such a scenario, there is an urgent need to adopt climate-resilient agricultural practices that can sustain productivity while minimizing risks. Among various crops, maize (*Zea mays* L.) has emerged as a promising candidate for climate-resilient agriculture. Known for its wide adaptability and multiple uses, maize is increasingly being recognized as a crop that can play a vital role in ensuring food security, enhancing farmer income and supporting sustainable agriculture under changing climatic conditions.

Maize: A Versatile and Resilient Crop

Maize is one of the most important cereal crops globally, often referred to as the “queen of cereals” due to its high productivity and versatility. It is cultivated across diverse agro-climatic zones, from rainfed regions to irrigated fields, making it a preferred crop for millions of farmers. In India, maize is used not only as a food grain but also as a key ingredient in animal feed, poultry industries, and various processed food products. Its demand has been steadily increasing due to the expansion of the livestock sector and industrial applications such as starch, ethanol, and bio-based products. What makes maize particularly important in the context of climate change is its adaptability. Compared to many other crops, maize can perform relatively well under varied environmental conditions, provided appropriate management practices are followed. However, despite its potential, maize productivity is still vulnerable to climatic stresses, highlighting the need for climate-smart interventions.

Climate Change and Its Impact on Maize

Climate change is affecting maize production in multiple ways, often reducing both yield and quality. High temperatures, especially during flowering, can severely impact pollination, leading to poor grain formation. Even a small increase in temperature during this stage can cause significant yield loss.

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Similarly, irregular rainfall patterns can lead to water stress or waterlogging, both of which are detrimental to maize growth. Drought remains one of the most serious threats, particularly in rainfed areas where irrigation facilities are limited. On the other hand, excessive rainfall and flooding can damage roots, reduce nutrient availability, and increase the risk of diseases. Climate change also influences the behaviour of pests and diseases. Warmer temperatures can increase pest populations and extend their active periods, leading to higher crop damage. These challenges clearly indicate that traditional farming practices alone are no longer sufficient. There is a need for a shift toward climate-resilient agriculture that focuses on adaptation, efficiency, and sustainability.

Climate-Resilient Strategies for Enhancing Maize Productivity

Selection of Improved and Stress-Tolerant Varieties: One of the most effective ways to combat climate stress is through the use of improved maize varieties. Drought-tolerant, heat-tolerant, and early-maturing hybrids have been developed to withstand adverse conditions. These varieties not only ensure stable yields but also reduce the risk of crop failure. Early-maturing varieties are particularly beneficial in areas prone to drought, as they complete their life cycle before severe stress conditions set in.

Optimum Sowing Time and Crop Planning: Adjusting sowing time is a simple yet powerful strategy to avoid climatic stress. By aligning planting schedules with favourable weather conditions, farm-

ers can protect crops from heat stress or water scarcity during critical growth stages. Proper crop planning, including crop rotation and diversification, also helps in reducing risks and improving soil health.

Efficient Water Management: Water management is crucial for maize productivity. Climate-resilient practices include:

- ✓ Use of drip and sprinkler irrigation systems
- ✓ Rainwater harvesting and storage
- ✓ Mulching to conserve soil moisture
- ✓ Timely irrigation during critical stages like flowering and grain filling

These practices not only improve water-use efficiency but also ensure better crop growth under limited water availability.

Soil Health Improvement: Healthy soil is the foundation of resilient agriculture. Practices such as the application of organic manure, compost, and green manure enhance soil fertility and structure. Integrated nutrient management, which combines organic and inorganic fertilizers, ensures balanced nutrition for crops. Improved soil health increases water retention capacity and supports better root development, making crops more resilient to stress.

Integrated Pest and Disease Management: Climate change can increase the incidence of pests and diseases, making crop protection an important aspect of climate-resilient agriculture. Eco-friendly pest management practices, such as the use of biological control agents, resistant varieties, and regular monitoring, help reduce crop losses while

maintaining environmental sustainability.

Adoption of Modern Technologies: Technological advancements are playing a key role in transforming agriculture. Tools such as weather forecasting systems, mobile-based advisory services, and precision farming technologies enable farmers to make informed decisions. Real-time information on weather conditions, soil moisture, and crop health helps in optimizing inputs and reducing risks.

Economic Benefits and Expanding Market Opportunities in Climate-Resilient Maize Farming:

Climate-resilient maize farming significantly enhances both productivity and profitability by promoting efficient resource use, reducing input costs, and ensuring stable yields even under climatic uncertainties. Practices such as improved varieties, efficient water management, and balanced nutrient use help minimize risks associated with drought, heat, and irregular rainfall. As a result, farmers experience more consistent and reliable income compared to traditional practices. Maize is a high-demand crop with diverse applications across food, feed, and industrial sectors. The rapid growth of the poultry and livestock industries has increased its demand as a primary feed ingredient. Additionally, expanding biofuel production and processed food industries have further strengthened market opportunities. Farmers can also benefit from value addition through processing into products like maize flour, starch, and animal feed. With proper market linkages, government support, and access to modern technologies, climate-resilient maize farming offers

a sustainable pathway for enhancing farmer income and long-term agricultural stability.

Challenges in Adoption: Despite its benefits, the adoption of climate-resilient practices faces several challenges:

- ✓ Lack of awareness and technical knowledge
- ✓ Limited access to quality seeds and technologies
- ✓ Financial constraints and initial investment costs
- ✓ Weak extension services and market linkages

Addressing these challenges requires coordinated efforts from government agencies, research institutions, and the private sector.

Future Prospects

The future of agriculture lies in resilience and sustainability. Climate-resilient maize production systems have the potential to ensure food security, improve farmer income, and reduce environmental impact. With advancements in research, technology, and policy support, maize can become a key crop in adapting to climate change. Encouraging farmer participation, promoting sustainable practices, and strengthening value chains will further enhance its potential.

Conclusion

Climate change is undoubtedly one of the greatest challenges facing agriculture today, but it also provides an opportunity to innovate and transform farming systems. Maize, with its adaptability and economic importance, holds great promise as a climate-resilient crop. By adopting improved varieties, efficient resource management practices, and modern technologies, farmers can enhance

maize productivity even under changing climatic conditions. A holistic approach that combines scientific knowledge, policy support, and farmer awareness is essential for building a resilient agricultural future. Climate-resilient agriculture is not just an option. And maize, as a versatile and promising crop, can play a central role in this transformation, ensuring sustainability, profitability, and food security for generations to come.



Kalmegh: A Green Gold Revolution in Farmer Income

Shashi Bhushan

Introduction

Agriculture in the 21st century is undergoing a profound transformation, shaped by the urgent need for sustainability, climate resilience, and improved farm profitability. Conventional cropping systems, though fundamental to food security, are increasingly constrained by shrinking landholdings, erratic weather patterns, soil degradation, and rising input costs such as fertilizers, irrigation, and labour. These challenges have significantly reduced profit margins for farmers, particularly small and marginal landholders. As a result, there is a growing shift toward crop diversification and the adoption of high-value, low-input alternatives that can ensure stable and enhanced income. In this evolving agricultural landscape, medicinal and aromatic plants have emerged as a promising solution. These crops not only require relatively fewer chemical inputs but also offer higher market value due to their extensive use in pharmaceuticals, nutraceuticals, and herbal industries. Their adaptability to diverse agro-climatic conditions and compatibility with organic farming systems further enhance their appeal. Among such crops, *Kalmegh* (*Andrographis paniculata*), popularly known as the “King of Bitters,” has gained considerable attention. Traditionally recognized in Ayurveda for its potent therapeutic properties, Kalmegh is now witnessing increasing commercial

demand, especially for its bioactive compound andrographolide, widely used in immunity-boosting and liver-protective formulations. The post-pandemic surge in demand for herbal medicines has further accelerated its market growth. With relatively low cultivation costs, short crop duration, and assured market demand, Kalmegh is emerging as a “green gold,” offering farmers a sustainable pathway to diversify income and reduce economic risks in modern agriculture.

Botanical Profile of Kalmegh

Kalmegh (*Andrographis paniculata*) is an annual herbaceous plant belonging to the family Acanthaceae. It is widely distributed across tropical and subtropical regions of India and Southeast Asia. The plant typically grows up to 30-110 cm in height, with dark green, lance-shaped leaves and small white flowers marked with purple spots. It thrives well in warm and humid climates and can be cultivated in a wide range of soil types, although well-drained loamy soils are considered ideal. Kalmegh is a hardy crop, adaptable to different agro-climatic conditions, making it suitable for cultivation across many parts of India.

Medicinal and Economic Importance

Kalmegh holds a prominent place in traditional systems of medicine such as Ayurveda, Siddha, and Unani. It is widely known for its therapeutic

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properties, including anti-inflammatory, antiviral, antibacterial, and hepatoprotective effects. The primary bioactive compound in Kalmegh is andrographolide, which is widely used in herbal formulations to boost immunity, treat liver disorders, manage infections, and improve overall health. In recent years, especially after the COVID-19 pandemic, there has been a surge in demand for immunity-boosting herbal products, further increasing the market value of Kalmegh. Economically, Kalmegh offers farmers a lucrative opportunity. The rising demand from pharmaceutical companies, herbal industries, and export markets ensures a stable and growing market. Compared to many traditional crops, Kalmegh requires relatively low inputs while offering higher returns, making it an attractive option for small and marginal farmers.

Cultivation Practices

Land Preparation: Kalmegh can be grown in a variety of soils, but well-drained sandy loam to loamy soils with good organic content are ideal. The land should be ploughed thoroughly to achieve a fine tilth, followed by levelling. Incorporation of organic manure such as farmyard manure (FYM) enhances soil fertility and improves crop growth.

Sowing and Propagation: The crop is propagated through seeds. Sowing is usually done at the onset of the monsoon (June-July), although it can also be cultivated under irrigated conditions. Seeds can be directly sown in the field or raised in nurseries and transplanted later. A seed rate of about 2-2.5 kg ha⁻¹ is recommended. Proper spacing (30 cm × 15 cm)

ensures optimal plant growth and yield.

Nutrient Management: Kalmegh responds well to organic cultivation practices. Application of FYM or compost at the time of land preparation is beneficial. If required, a balanced dose of nitrogen, phosphorus, and potassium can be applied to enhance growth and biomass production.

Irrigation Management: The crop is moderately tolerant to drought but performs best under adequate moisture conditions. During the rainy season, irrigation may not be necessary; however, supplemental irrigation is required during dry spells to ensure proper growth.

Weed and Pest Management: Weed management is crucial during the initial stages of crop growth. Two to three manual weeding's are generally sufficient. Kalmegh is relatively less susceptible to pests and diseases, which reduces the need for chemical inputs. Eco-friendly pest management practices are recommended to maintain the medicinal quality of the crop.

Harvesting and Post-Harvest Management: Kalmegh is typically ready for harvest 90-120 days after sowing, when the plants attain full vegetative growth and begin flowering. The entire aerial part of the plant is harvested by cutting it close to the ground. Post-harvest handling plays a critical role in maintaining quality. The harvested plants are cleaned and dried under shade to preserve their active constituents. Proper drying ensures better storage and higher market value. The dried material is then packed and stored in moisture-free conditions.

Value addition through processing, such as powdering or extraction, can further enhance the profitability of the crop.

Economic Analysis and Profitability: Kalmegh cultivation offers a favourable cost-benefit ratio. The cost of cultivation is relatively low due to minimal input requirements and reduced pest management expenses. Under proper management, the crop can yield approximately 2-3 tonnes of dry herb per hectare. The market price varies depending on quality and demand but generally remains attractive due to its high medicinal value. Farmers cultivating Kalmegh often report higher net returns compared to traditional crops like cereals and pulses. Additionally, the crop's short duration allows farmers to fit it into existing cropping systems, thereby increasing overall farm productivity.

Market Potential and Scope: The market for medicinal plants, including Kalmegh, is expanding rapidly at both national and international levels. The growing awareness of herbal medicine, coupled with increasing health consciousness, has fuelled demand. India, being rich in biodiversity and traditional knowledge, holds a strong position in the global herbal market. Kalmegh is widely used by pharmaceutical companies, herbal product manufacturers, and nutraceutical industries. There is also significant export potential, particularly to countries where herbal and natural remedies are in high demand. Contract farming and linkages with herbal industries can provide farmers with assured markets and better prices. Government initiatives promoting medicinal

plant cultivation further support the expansion of Kalmegh farming.

Challenges in Kalmegh Cultivation

Despite its potential, Kalmegh cultivation faces certain challenges. Lack of awareness and technical knowledge among farmers limits its adoption. Many farmers are still unfamiliar with cultivation practices, market linkages, and post-harvest management. Market fluctuations and a lack of organized marketing systems can also affect profitability. Quality standards and certification requirements for export markets pose additional challenges. Moreover, limited availability of processing and storage facilities can lead to post-harvest losses and reduced returns.

Future Prospects

Kalmegh has immense potential to contribute to sustainable agriculture and rural development. Its adaptability, low input requirements, and high economic returns make it suitable for climate-resilient farming systems. Integration of Kalmegh into crop diversification strategies can enhance farm income and reduce dependency on conventional crops. It also aligns well with organic and natural farming practices, which are gaining popularity among farmers and consumers alike. With proper support for training, research and market development, Kalmegh cultivation can emerge as a key driver of agripreneurship and rural employment.

Conclusion

Kalmegh truly embodies the concept of “green gold” in modern agriculture. Its medicinal

importance, rising market demand, and economic viability make it a promising crop for farmers seeking sustainable and profitable alternatives. By adopting Kalmegh cultivation, farmers can diversify their income sources, reduce risks, and contribute to the growing herbal economy. However, to fully realize its potential, there is a need for increased awareness, better infrastructure, and supportive policies.

As agriculture continues to evolve, crops like Kalmegh offer a pathway toward a more resilient, sustainable, and prosperous farming future.



Significance of 16S rRNA Gene in Detection of Bacterial Pathogens

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Introduction

Plant Bacteriology is a branch of plant pathology which deals with plant diseases caused by prokaryotes such as actinobacteria, proteobacteria, mollicutes etc. They cause many serious diseases of plants throughout the world and cause heavy economic losses (Vidhyasekaran, 2002). Accurate detection of the causal agent is crucial to understand the factors favoring the disease and to devise specific and effective management strategies. Hence, potent and efficient techniques must be employed for detection of bacterial pathogens.

Techniques used for identification of plant pathogenic bacteria

Conventional techniques: The conventional techniques used for identification of bacteria involves the use of phenotypic tools like colony and cell morphology, physiology, biochemical behavior etc. Examples include shape, presence or absence of flagella, arrangement of flagella, substrate utilization, Gram staining etc. These traditional methods suffer from several limitations, which include:

- ✓ They are time-consuming and laborious.
- ✓ Variability of culture due to different environmental conditions may lead to ambiguous results.
- ✓ Phenotypic characterization might be reliable up to identification of genera but distinct differentiation might not be obtained between related

species or strains of bacteria.

- ✓ Pure culture is required to undertake identification, making the identification of fastidious and unculturable bacteria difficult and sometimes impossible.

To evade these problems, genotypic methods, *i.e.*, the use the bacterial DNA sequence as a tool for discrimination and identification became popular. Instead of using the whole genome sequence of the bacterium for identification, which is laborious and uneconomical, it is more advantageous to use certain conserved regions which show minor variations from bacteria to bacteria.

Ribosomal RNA genes are such regions in bacterial DNA that are convenient measure for taxonomy and detection of bacteria (Woese *et al.*, 1990). Among the three types of RNA that are contained by bacterial ribosomes, namely, 16S rRNA, 5S rRNA and 23S rRNA, the 16S rRNA is regarded as the most useful and reliable measure. 16S rRNA stands for 16S ribosomal ribonucleic acid (rRNA), where S (Svedberg) is a unit of measurement (sedimentation rate). This rRNA is an important constituent of the small subunit (SSU) of prokaryotic ribosomes as well as mitochondria and chloroplasts.

Why is 16S rRNA chosen as DNA barcode molecule for identification and taxonomy of bacteria

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- ✓ It is ubiquitously present; all members of Bacteria and Archaea are known to have 16S rDNA gene.
- ✓ 16S rDNA is about 1,500 bp long, which is an acceptable length and contains sufficient phylogenetic information.
- ✓ The sequence is conserved but has sufficient variation to distinguish between taxa (Gutell *et al.*, 1985; Noller, 1984).

Sequence variation among bacterial 16S rDNA is not uniformly distributed. Nine hypervariable regions were identified within the gene sequence, which are named V1 to V9. The full-length 16S gene is usually amplified by the pair of primers 27F and 1492R, followed by Sanger DNA sequencing. Specific primers can also be used to amplify individual variable regions.

Steps in Bacterial Detection using 16S r RNA sequence

Through sequence analysis of 16s r DNA region

- ✓ Isolation of DNA from crude sample
- ✓ Amplification of 16s r DNA region using universal primers
- ✓ Validating and purifying the PCR product through Agarose Gel Electrophoresis
- ✓ Sequencing the PCR Product using Sanger's Dideoxy sequencing or Next Generation sequencing techniques.
- ✓ Sequences are subjected to a BLAST analysis (Altschul *et al.*, 1997) with the NCBI database.
- ✓ A sequence similarity of the 16S rDNA test sequence of more than 98.65% with the database

sequence is used as a threshold to establish species identity (Kim *et al.*, 2014)

RFLP (Restriction fragment length polymorphism) analysis of 16S rRNA gene

- ✓ DNA isolation
- ✓ Amplification of the 16s rThe PCR products are digested with a restriction enzyme.
- ✓ The fragments are separated by electrophoresis
- ✓ The fragment lengths indicate the diversity that is in the analysed sample. Example: Different *Aerobacter* species displays different RFLP banding pattern of the 16S rRNA gene (Figueras *et al.*, 2012) (Fig. 1).

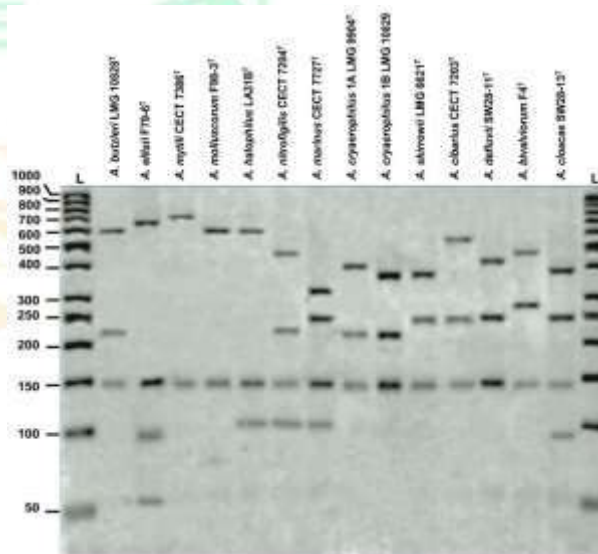


Fig. 1: Differences in 16S r DNA RFLP band pattern amongst different *Aerobacter* species (Figueras *et al.*, 2012)

Temperature gradient gel electrophoresis/ denaturing gradient gel electrophoresis of 16S rDNA amplicon:

These methods exploit the different denaturing properties of double-stranded 16S rRNA gene copies with sequence differences. The base differences in the 16S rRNA gene determine the stage of electrophoresis at which the double-stranded 16S

rRNA gene melts in a gel with either a temperature or a denaturing chemical gradient. These denaturing differences can correspond to variation in the position of the bands. Small sequence differences between 16S rRNA gene strands can be detected by these methods (Muyzer *et al.*, 1993). Kalyuzhnaya *et al.* (2008), demonstrated the use of denaturing gel electrophoresis for differentiating the methylotrophic bacteria.

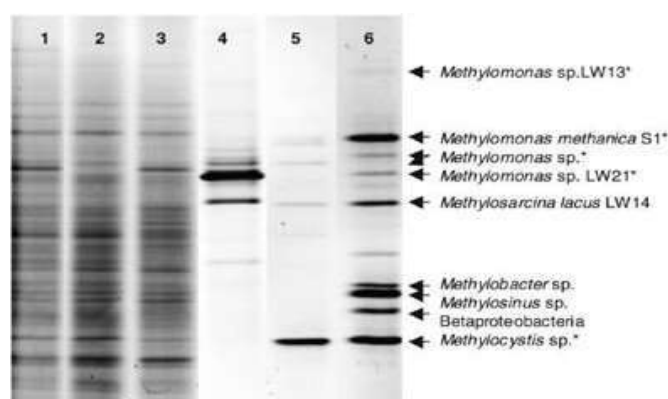


Fig. 2: Denaturing gradient gel electrophoresis (DGGE) analysis of amplified 16S rRNA gene fragments of different bacteria (Kalyuzhnaya *et al.*, 2008)

Antages of Bacterial Detection using 16s r RNA Gene

- ✓ This method of bacterial identification is culture-independent and only requires DNA of the tested bacteria.
- ✓ Variable regions of the 16S rRNA gene have also been reported to allow species identification.
- ✓ The development of NGS techniques, including 16S rRNA next-generation sequencing (16SNGS), allows further upscaling of sequencing quantity (fragments versus time) even in mixed cultures, enabling bacterial detection in environmental samples through meta-barcoding.

Limitations

- ✓ 16S r DNA sequencing requires procurement of costly equipment, timely sustainable maintenance of these platforms, development of specific laboratory infrastructure and training of technical expertise, all of which are still challenges even for middle-income countries.
- ✓ Bacterial characterisation cannot be done solely on the basis of 16s r RNA gene sequence data. It has to be verified using morphological and culture-based tests.
- ✓ The primers used for amplification will introduce a bias as they bind to regions that are not 100% conserved across all bacteria.

Conclusion

Approaches to identifying and studying bacterial diversity often relied on the traditional methods of plating bacteria on agar. These approaches are still relevant for culturable bacteria but fall short of detecting fastidious and unculturable bacteria. Molecular-based techniques like targeted sequencing of the 16S rRNA have facilitated surveys of bacterial diversity and bacterial disease diagnostics. Detection using 16s r RNA gene sequence has helped overcome all limitations of conventional detection techniques.

References

- Figueras, M. J., Levican, A. and Collado, L. (2012). Updated 16S rRNA-RFLP method for the identification of all currently characterised *Arcobacter* spp. *BMC Microbiology*, 12(1): 92.

- Altschul, S. F., Madden, T. L., Schäffer, A. A., Zhang, J., Zhang, Z., Miller, W. and Lipman, D. J. (1997). Gapped BLAST and PSI-BLAST: a new generation of protein database search programs. *Nucleic Acids Research*, 25(17): 3389-3402.
- Gutell, R. R., Weiser, B., Woese, C. R. and Noller, H. F. (1985). Comparative anatomy of 16-S-like ribosomal RNA. *Progress in Nucleic Acid Research and Molecular Biology*, 32: 155-216.
- Kalyuzhnaya, M. G., Lidstrom, M. E. and Chistoserdova, L. (2008). Real-time detection of actively metabolizing microbes by redox sensing as applied to methylotroph populations in Lake Washington. *The ISME Journal*, 2(7): 696-706.
- Kim, M., Oh, H. S., Park, S. C. and Chun, J. (2014). Towards a taxonomic coherence between average nucleotide identity and 16S rRNA gene sequence similarity for species demarcation of prokaryotes. *International Journal of Systematic and Evolutionary Microbiology*, 64(Pt 2): 346-351.
- Muyzer, G., De Waal, E. C. and Uitterlinden, A. (1993). Profiling of complex microbial populations by denaturing gradient gel electrophoresis analysis of polymerase chain reaction-amplified genes coding for 16S rRNA. *Applied and Environmental Microbiology*, 59(3): 695-700.
- Noller, H. F. (1984). Structure of ribosomal RNA. *Annual Review of Biochemistry*, 53(1): 119-162.
- Woese, C. R., Kandler, O. and Wheelis, M. L. (1990). Towards a natural system of organisms: proposal for the domains Archaea, Bacteria, and Eucarya. *Proceedings of the National Academy of Sciences*, 87(12): 4576-4579.

Predatory Insects: Their Various Roles and Benefits

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Abstract

Predatory insects are vital components of sustainable agriculture and environmental monitoring, serving as both natural biocontrol agents and sensitive bioindicators. This document examines the efficacy of key taxa including Coccinellidae, Chrysopidae, Phytoseiidae and Anthocoridae in managing devastating pests like aphids, thrips, and mealybugs within Integrated Pest Management frameworks. By suppressing pest populations below economic thresholds, these predators reduce chemical reliance, enhance biodiversity, and stabilize global crop yields. Beyond pest suppression, predatory insects across orders such as Coleoptera, Odonata, and Hemiptera function as “ecological thermometers.” Species like *Pterostichus oblongopunctatus* and *Gerris spp.* provide critical data on heavy metal bioaccumulation and habitat degradation. The synthesis highlights that fostering predator diversity through habitat conservation and mass-rearing strategies is essential for resilient agro-ecosystems. Ultimately, leveraging the predatory roles of these organisms offers a sophisticated, eco-friendly approach to mitigating both agricultural damage and environmental pollution.

Introduction

To address the rising threats of pesticide resistance and environmental pollution, both global and Indian agriculture are shifting toward biological control through Integrated Pest Management (IPM). Predatory insects such as *Coccinella septempunctata*, *Cryptolaemus* and *Chrysoperla* act as a natural “security force,” regulating pests like aphids and mealybugs to boost crop yields sustainably. Apart from pest control, these organisms serve as vital bioindicators; their high sensitivity to pollutants provides an early warning system for ecosystem distress and chemical contamination.

While these hunters restore ecological balance and ensure food security, Furlong *et al.* (2010) note that certain drawbacks in their utilization highlight the need for further scientific study to optimize their role in diverse agro-ecosystems.

Some Predators and their role in pest control

Predatory insects like lady beetles and lacewings provide a resilient alternative to pesticides by targeting pests throughout their life cycles. By integrating these natural enemies into Integrated Pest Management (IPM) through habitat diversity, farmers can maintain pest populations below economic thresholds while fostering biodiversity (Furlong *et*

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al., 2010). Ultimately, leveraging these interactions ensures stable crop yields and long-term ecosystem health (Luff, 1983).

Ladybird Beetles: Coccinellid beetles, or ladybirds, are essential biological control agents that provide an economical and eco-friendly alternative to synthetic pesticides. Their high consumption rates and rapid reproduction allow them to maintain pest populations below economic thresholds, ensuring long-term agricultural stability (Johari *et al.*, 2020). In Indian agro-ecosystems, species like *Cryptolaemus montrouzieri* are specifically deployed to manage mealybugs in citrus and coffee, while *Coccinella septempunctata* effectively represses aphid populations in wheat and mustard crops. To ensure optimal suppression in both open fields and greenhouses, these predators are typically released at intervals of 10-20 days (Kshitiz *et al.*, 2021).

Lacewings: Green lacewings, particularly *Chrysoperla carnea*, are essential generalist predators in Integrated Pest Management (IPM), valued for the voracious appetite of their larvae against soft-bodied pests like aphids, thrips, and mealybugs. While adults are rarely used for bulk releases due to handling costs, the aggressive first and second-instar larvae are highly effective in both open fields and greenhouses (Kothuri *et al.*, 2025). Recommended release rates vary by environment: 75,000-100,000 eggs per hectare for vegetables like tomato and cabbage, 50,000-75,000 eggs for fruit crops like grapes and citrus, and 5,000-10,000 eggs per 100 metre square for polyhouse crops like cucumber.

Consistent monitoring and re-releases every 10-15 days ensure sustained protection and healthier crop growth (Venzon *et al.*, 2021).

Predatory Bugs: Predatory mirid bugs, such as *Cyrtorhinus lividipennis*, are vital for managing rice hoppers, with release rates of 100-250 adults per hectare during early colonization (Ahmed *et al.*, 2018). Similarly, generalist anthocorid bugs (*Orius spp.*) effectively target thrips, aphids, and whiteflies in both greenhouses and open fields (Stansly *et al.*, 2005). These “pirate bugs” are also deployed at rates up to 10,000 individuals ha⁻¹ to suppress spider mites and lepidopteran eggs, ensuring robust crop protection across diverse agricultural settings (Karut *et al.*, 2022).

Spiders: Spiders manage pest populations through both direct predation and non-consumptive methods, such as disrupting pest feeding and reproductive behaviours. Their effectiveness is influenced by the specific crop type, pest species, and the overall diversity of the spider community. While they are highly aggressive hunters of aphids and caterpillars, their impact can be moderated by cannibalism and interactions with other beneficial arthropods (Daniel *et al.*, 2021).

Predatory Mites: Predatory mites, particularly the Phytoseiidae family, are essential for augmentative biological control due to their rapid reproduction and ability to target diverse pests. *Phytoseiulus persimilis* serves as a specialist against spider mites, with recommended release rates of 2,000-5,000 ha⁻¹ (Khajuria *et al.*, 2009; Knapp *et al.*, 2018).

Generalist species like *Amblyseius swirskii* provide preventive protection by feeding on pollen or thrips, typically deployed at 50-100 mites per square meter (Van Lenteren *et al.*, 2018). Despite monitoring challenges, these mass-producible mites remain economically viable cornerstones for sustainable greenhouse and field agriculture.

The role of different orders of predatory insect in environmental pollution indication:

Coleoptera: Predatory beetles are essential bioindicators for assessing ecosystem health and contamination. Soil-dwelling Carabidae, such as *Pterostichus oblongopunctatus*, exhibit morphological changes near lead and zinc smelters, while *Carabus lefebvrei* is used to monitor arsenic and mercury (Lagisz, 2008). In India's Bhosga reservoir, aquatic families like Dytiscidae, Hydrophilidae, and Gyrinidae reflect water quality; notably, moderately pollution-sensitive families comprised 74.11% of the population, indicating a healthy ecosystem (Sarika and Vijaykumar, 2022). Furthermore, species like *Hydroglyphus pusillus* and *Laccophilus minutus* effectively accumulate trace elements (Burgelea *et al.*, 2011), while tiger beetles serve as "habitat thermometers" (Pearson and Pearson, 2014). Finally, population declines in these predators can signal pesticide contamination and its sub-lethal effects on natural enemies (Duso *et al.*, 2020; Bordini *et al.*, 2021).

Diptera: Syrphid flies, belonging to the family Syrphidae, are significant for evaluating the biological diversity of their surroundings because of their

rapid adult mobility (Sommaggio, 1999). *Eristalis* spp. and *Sphaerophoria* spp. capture heavy metals, such as manganese, lead, and cadmium, in their bodies from the industrial zone (Markova and Alexiev, 2001). These metals bind with metallothionein and are sequestered in tissues such as the fat body and gut, indicating environmental contamination levels and rendering these species good bioindicators of industrial pollution.

Ephemeroptera: Mayflies are ancient aquatic insects that serve as premier bioindicators due to their nymphs' extreme sensitivity to environmental shifts in oxygenated waters (Jacobus *et al.*, 2019). Research shows that larvae, such as *Ephemera danica*, reliably reflect heavy metal accumulation from industrial sources, like trout farm effluents, making them effective tools for measuring sediment pollution (Božanić *et al.*, 2019). Furthermore, species like *Siphonurus* are increasingly vulnerable to microplastic contamination, as they have been found to ingest synthetic polymers like polyester and ABS (Akindele *et al.*, 2020).

Hemiptera: Aquatic hemipterans are vital tools for monitoring freshwater health, serving as both biocontrol agents and bioindicators. Water striders like *Gerris* spp. effectively accumulate heavy metals such as mercury and cadmium, providing a direct link to industrial contamination (Nummelin *et al.*, 1998). Similarly, species within the Corixidae family reflect shifting eutrophication levels in their habitats (Bakonyi *et al.*, 2022). Research on *Ilyocoris cimicoides* confirms that heavy metal exposure cau-

ses measurable oxidative stress and DNA damage, reinforcing these insects' reliability as indicators for aquatic pollution (ElSamad *et al.*, 2024).

Hymenoptera: Ants (Formicidae) and wasps (*Vespula*) are vital bioindicators for monitoring ecosystem health and industrial impact. Ants are particularly useful for detecting adverse changes in soil quality and providing early warning systems for environmental degradation (Underwood and Fisher, 2006). Human activity directly alters ant nest distribution; for example, *Lasius niger* typically builds more underground nests near industrial pollutants (Blinova and Dobrydina, 2019), while *Formica lugubris* workers show physical changes, such as reduced head melanization, in contaminated zones (Skaldina *et al.*, 2018). Similarly, wasps like *V. vulgaris* serve as effective indicators of atmospheric pollution because their active foraging leads to the accumulation of heavy metals including iron (Fe), nickel (Ni), and copper (Cu) both internally and on their body surfaces (Skaldina *et al.*, 2023).

Neuroptera: The presence of antlions, belonging to the family Myrmeleotidae, indicates the overall health of a specific ecosystem (Nummelin *et al.*, 2007). Their inclination on stable, undisturbed sandy locations for survival signifies that the soil is comparatively healthy. A reduction in antlion numbers may indicate habitat disruption, resulting from urbanization or climate change. Antlion larvae, as ambush predators, remain in a specific soil patch for extended durations, accumulating metals from their surroundings and the prey they ingest.

Odonata: The order Odonata, which includes dragonflies and damselflies, serves as a premier bioindicator for freshwater health. Because they have well-documented life cycles and are highly sensitive to environmental shifts, their presence or absence reflects the integrity of an aquatic ecosystem. Both larvae and adults respond to fluctuations in water quality, including pH levels, heavy metals (like iron and nickel), and chemical pollutants such as methylmercury. Known as “guardians of the watershed,” their population density and breeding habits provide a reliable, visible measure of habitat quality and pollution levels without the need for complex chemical testing.

Role of predator and Prey insects in ecosystem

Insects often labelled as “pests” are actually vital components of a healthy ecosystem; they cull weak plants and provide a foundational food source for birds, reptiles, and larger predators. Predatory insects maintain this balance by naturally regulating pest populations, preventing them from causing widespread damage. By fostering both groups, you create a self-sustaining mini-ecosystem where nature manages its own growth and survival through a complex food web.

Benefits of using Predatory insects: Biological pest control offers a safer, more sustainable alternative to synthetic chemicals. Because predatory insects (and the vast majority of harmless spiders) are non-toxic, they pose no risk to humans or pets. This organic approach preserves local biodiversity and aligns with environmental health. Furthermore, while chemical

treatments are temporary and often require reapplication, a settled population of predatory insects provides a long-term, self-perpetuating solution for garden maintenance.

Creating the Perfect Environment for Attracting

Predatory Insects: To attract and retain predatory insects, we must establish a diverse environment that mirrors a natural ecosystem. This begins with plant diversity, specifically including species with small flowers like alyssum and callistemon to provide necessary nectar and pollen. Beyond food, these “beneficials” require shelter, such as leaf litter, dead wood, or insect hotels, and a consistent water source like a shallow pebble dish. Crucially, we must avoid broad-spectrum pesticides and tolerate a small population of pests; without a consistent food source, predatory insects will not stay in your garden.

Identification and Sourcing: Effective biological control starts with accurately identifying the pests causing damage through careful observation of plant symptoms or insect behaviour. If we are unsure of the species, we can consult horticultural experts or use digital resources like Bugs for Bugs to identify the problem before acting. Once the pest is confirmed, we can source healthy, compatible predators from reputable online suppliers to provide immediate relief while our garden’s natural defenses are still becoming established.

Strategic Release Techniques: Successful integration of purchased insects depends on specific releasing techniques tailored to the species and environment. Some predators must be placed directly

onto infested foliage, while others should be released near specific habitats or host plants to encourage colonization. Timing is also a critical factor; for instance, releasing insects at dusk can prevent them from being immediately targeted by birds or becoming dehydrated by the midday sun. Always consult our supplier for species-specific advice to ensure the highest survival and establishment rates.

Benefits of predatory insects to India and the

world: Predatory insects act as vital natural pest control agents in India and globally by regulating harmful pest populations (aphids, caterpillars, whiteflies) in agriculture, reducing reliance on chemical pesticides, and enhancing crop yields. Key species like ladybugs, lacewings, and predatory mites protect crops such as cotton, citrus, and vegetables. **Natural Pest Control (Biocontrol):** Predatory insects (e.g., Coccinellid beetles, green lacewings) prey on harmful pests like thrips, mealybugs, and mites, protecting crops without chemicals. In India, using native predators (like *Amblyseius* mites) helps decrease toxic insecticide use, lowering production costs and ecological footprints. By reducing pest damage to crops, predators like ladybugs and predatory mites significantly contribute to improved agricultural productivity. Predatory insects help maintain ecological balance, often thriving in diverse agricultural landscapes (e.g., fruit orchards). They are key components of Integrated Pest Management (IPM), promoting long-term sustainable agriculture.

Conclusions

Predatory insects are the backbone of sustain-

able Integrated Pest Management (IPM), offering a biological alternative to chemicals that boosts both crop yields and biodiversity. Because no single predator can tackle every threat, IPM relies on a strategic mix of hunters: Green Lacewings act as versatile generalists against aphids and thrips; Ladybird Beetles specialize in mealybugs and scale insects; Mirid Bugs protect rice from planthoppers; and Predatory Mites provide rapid control in greenhouses. Even spiders contribute by disrupting pest behaviour. To maximize these benefits, the scientific community is focused on developing economical mass-rearing diets and studying the complex “tri-trophic” interactions between plants, pests, and predators across different climates. Beyond their role as hunters, these insects are sophisticated bioindicators of environmental health. Occupying high trophic levels makes them acutely sensitive to contaminants, allowing their population shifts to serve as an “early warning system” for ecological distress. While monitoring these populations requires an initial investment, the resulting data is invaluable for preventing habitat degradation and managing pollutants. Ultimately, integrating predatory insect conservation into land management is essential for building resilient, chemical-free ecosystems

References

<https://doi.org/10.9734/jabb/2025/v28i62516>

<https://doi.org/10.56557/upjoz/2025/v46i205311>

University of Maryland Extension.

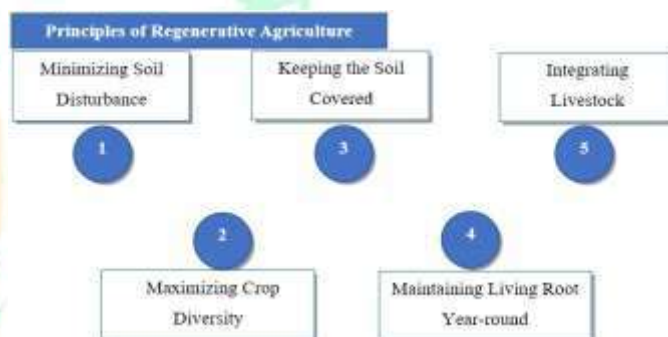
Introductory predator pest to reduce garden pest populations by Greenlife Ozbreed website.

Regenerative Agriculture: A Sustainable Approach for Crop Production in Stress-Prone Environments

G. Bhavani and Ashwini G.

Agriculture is extremely vulnerable to climate change spurred by human activity, which is causing rising temperatures and unpredictable weather. The problem is made worse by conventional farming methods that use chemicals, monoculture, and soil-degrading approaches. Crop productivity is decreased by environmental conditions such as water stress, nutritional deficiency, high or low temperatures, chemical (saline, alkaline and acidic soils), physical soil challenges (compaction, erosion), and biotic factors. In light of this, Regenerative Agriculture (RA) presents an answer to environmental problems by re-framing farming as a connected ecosystem. It reduces climate change and increases food security by emphasizing biodiversity, water conservation, and soil health. Another characteristic of regenerative approaches is diversity, both in terms of the crops cultivated and the inclusion of livestock. A balance that is frequently lacking in monoculture systems is fostered by polyculture and agroforestry systems, which optimize resource utilization and contribute to improved biodiversity. In addition to giving farmers new revenue sources, carefully managed livestock also improves soil fertility and nutrient cycling. Monoculture frequently result in increased weed pressure. Pest problems might be made worse by a lack of crop diversity.

Growing a variety of crops on the same piece of land for a set period of time is known as crop diversification. This strategy can be used either sequentially or simultaneously and aims to increase overall productivity, sustainability, and resilience. The most effective method for creating an effective and sustainable production system is to use ecological weed and pest control techniques in diversified farming (Sharma *et al.*, 2021).



From a conceptual standpoint, RA is not a single technology but rather an innovative process that requires education for farmers and other stakeholders. This process entails regenerating the top soil, increasing biodiversity, and improving input-use efficiency. Potential advantages of zero tillage (ZT) over traditional or conventional methods include less water use, carbon (C) sequestration, comparable or greater yield and higher revenue, lower fuel consumption, lower greenhouse gas emissions, and greater heat stress tolerance. Crop diversification is a crucial adaptation tactic that farm-

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ers can use to mitigate the negative impacts of extreme weather conditions like droughts. Compared to conventional and traditional approaches, crop residue management and mulching may provide the following advantages: regulating soil moisture and temperature; enhancing soil quality; decreasing soil erosion; lowering evaporation losses and retaining soil moisture; boosting C-sequestration; preventing burning and minimizing environmental pollution; enhancing heat stress tolerance; and decreasing weed proliferation (Jat *et al.*, 2021). The key to RA is combining grasslands, crops, and livestock. There is a substantial quantity of livestock manure and urine produced, which, when used wisely in conjunction with other fertilizer sources, will not only lower greenhouse gas emissions but also optimize INM in RA systems. A significant portion of land is impacted by issues with fluoride (Rajasthan), arsenic (Bengal Delta Plains), selenium (Punjab), etc. Crop-livestock systems with appropriate use of livestock excreta (dung and urine) could offer an opportunity as part of a solution to these concerns and contribute to progress towards increased use of RA.

Conclusion

Regenerative agriculture has enormous potential to improve soil health, increase biodiversity, mitigate climate change and redefine the relationship between humans and land. Regenerative farming empowers farmers to take care of the soil that produces our food, serving as stewards of the planet. RA practices reduce biotic and abiotic stresses through crop diversification, residue management,

zero tillage and livestock integration. Overall it offers a practical solution for environmental resilience and sustainable food security.

References

- Jat, H. S., Datta, A., Choudhary, M., Sharma, P. C. and Jat, M. L. (2021). Conservation Agriculture: factors and drivers of adoption and scalable innovative practices in Indo-Gangetic plains of India-a review. *International Journal of Agricultural Sustainability*, 19(1): 40-55.
- Sharma, G., Shrestha, S., Kunwar, S. and Tseng, T. M. (2021). Crop diversification for improved weed management: A review. *Agriculture*, 11 (5): 461.

Women in Indian Agriculture: Participation without Power

M. Chanakya, K. Prabhavathi, C. Ashwini and D. Ashwini

Women constitute a significant share of India's agricultural workforce, yet their contribution often remains invisible in policy and economic discussions. Estimates suggest that women account for roughly 40-64 percent of India's agricultural workforce, making them central to the functioning of rural economies. More importantly, over 75 percent of rural women are engaged in agriculture and allied activities, a phenomenon widely described as the "feminisation of agriculture." This shift has been largely driven by male out-migration from rural areas to urban centres in search of non-farm employment. The term feminisation of agriculture refers to the increasing participation and responsibility of women in agricultural activities as men migrate to non-farm employment and rural labour patterns change.

Recent labour statistics further highlight this trend. Data from the Periodic Labour Force Survey 2023-24 indicates that 64.4 percent of female workers in India are employed in agriculture, compared with 36.3 percent of male workers. This clearly demonstrates the increasing dependence of Indian agriculture on women's labour. In rural India, women's participation is even more pronounced. Studies indicate that approximately 76.95 percent of rural women are engaged in agriculture and allied sectors, accounting for nearly one-third of the total agricultural workforce.

Women undertake a wide range of farm operations, including sowing, transplanting, weeding, harvesting seed processing, livestock management, and post-harvest handling. Many of these tasks are highly labour-intensive and time-consuming, yet they often go unrecognized in official statistics because women frequently work as unpaid family labour on household farms. Despite their extensive participation, women's control over productive resources remains extremely limited, which directly affects farm productivity, income generation, and overall agricultural growth. One of the most critical constraints is land ownership. According to data from the Agriculture Census of India, women operate only about 10.34 percent of agricultural landholdings, and overall land ownership among women farmers remains around 12.8 percent. Without formal land titles, women farmers often struggle to access institutional credit, crop insurance, and government subsidy programmes, which are usually linked to land ownership.

Another important factor behind the feminisation of agriculture is the increasing migration of male workers from rural areas. As men move to cities for employment in construction, manufacturing, and service sectors, women are increasingly taking responsibility for managing farms and agricultural households. Studies suggest that female participation

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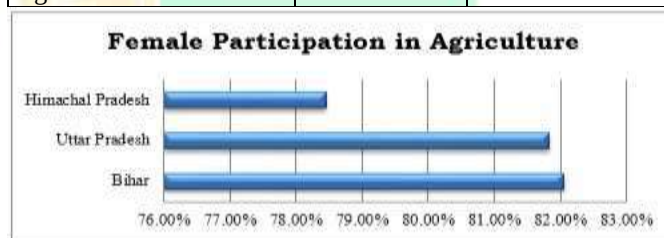
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in agriculture has increased by nearly 135 percent over the past decade, reflecting a major structural shift in rural labour dynamics. However, the growing presence of women in agriculture has not translated into equal economic benefits. A significant gender wage gap persists in the agricultural labour market. In many regions, women receive only 60-70 percent of the wages earned by men for similar work, highlighting deep-rooted inequalities in rural labour systems. Regional variations further illustrate the extent of women's involvement in agriculture. States such as Bihar, Uttar Pradesh, and Himachal Pradesh report particularly high female participation in agricultural activities, with rates reaching 82.06 %, 81.83 % and 78.45 %, respectively. These patterns demonstrate that women's labour forms the backbone of agricultural production in several parts of the country. Despite their immense contribution, women farmers continue to face multiple structural challenges. Limited land ownership, restricted access to institutional finance, inadequate extension services, and heavy reliance on manual labour reduce their productivity and economic independence. These barriers prevent women farmers from fully participating in modern agricultural value chains and limit their potential to contribute to rural economic growth. Addressing these structural gaps is essential for achieving inclusive agricultural development. Empowering women farmers through improved land rights, better access to credit, targeted extension services, and gender-responsive agricultural policies can significantly enhance productivity and streng-

then rural livelihoods. Recognizing women not merely as agricultural labourers but as independent farmers and decision-makers is therefore a crucial step toward building a more resilient and equitable agricultural sector in India.

Key Statistics: Women in Indian Agriculture

Indicator	Statistics	Source
Share of women in agricultural workforce	40-64%	Various labour studies
Female workers engaged in agriculture (2023-24)	64.4%	Periodic Labour Force Survey 2023-24
Male workers engaged in agriculture	36.3%	Periodic Labour Force Survey 2023-24
Rural women engaged in agriculture & allied sectors	76.95%	Research estimates
Women operating agricultural land holdings	10.34%	Agriculture Census of India
Overall land ownership by women farmers	~12.8%	Agricultural census estimates
Gender wage gap in agriculture	Women earn 60-70% of male wages	Labour studies
Increase in female participation in agriculture	~135% rise in last decade	Research reports



In recent years, the Government of India has taken several steps to support women in agriculture through programmes such as Mahila Kisan Sashaktikaran Pariyojana and initiatives promoting women Self-Help Groups under the National Rural Livelihood Mission. However, gaps in implementation and awareness continue to limit their full impact.

Policy Recommendations for Empowering Women Farmers

To unlock the full potential of women farmers, India's agricultural policies must adopt a gender-responsive approach. The following measures can play a crucial role in strengthening women's participation and productivity in agriculture:

Strengthening Land Rights: Ensuring joint land titles and inheritance rights for women can improve their access to institutional credit, crop insurance, and government schemes.

Gender-Responsive Agricultural Extension: Agricultural universities, research institutions, and extension services should design training programmes specifically targeting women farmers.

Expanding Institutional Credit Access: Special credit lines and collateral-free loans for women farmers can enhance their capacity to invest in improved technologies and farm inputs.

Promoting Women-Led Farmer Producer Organisations (FPOs): Encouraging women's participation in FPOs and cooperatives can strengthen market access and improve bargaining power.

Reducing Drudgery through Women-Friendly Farm Tools: Developing lightweight and ergonomic agricultural machinery suited for women can significantly reduce physical labour.

Bridging the Digital Divide: Providing digital literacy and access to mobile-based agricultural advisory services can help women farmers receive timely information on weather, markets, and crop management.

Strengthening Gender Budgeting in Agriculture: Allocating targeted funds within agricultural devel-

opment programmes ensures that women farmers receive equitable benefits from public investments. India's agricultural future cannot be secured without recognizing and strengthening the role of women farmers. While women contribute a substantial share of agricultural labour, their limited access to land, credit, technology, and decision-making continues to constrain their potential. Bridging these structural gaps through gender-responsive policies, institutional support and inclusive agricultural development strategies can unlock a powerful engine of rural growth. Empowering women farmers is therefore not only a question of social justice but a strategic imperative for achieving sustainable agriculture, food security, and resilient rural economies.

References

- Periodic Labour Force Survey, 2023-24.
- Agriculture Census of India.
- NITI Aayog Reports on Women in Agriculture
- ORF Research Reports on Feminisation of Agriculture.

Co-evolutionary and Competitive Mechanisms in the Plant Microbiome Underlying Community Fitness and Pathogen Suppression

Preeti Vashisht, Vinod Kumar Malik and Prahlad

Introduction

Plants are sessile organisms anchored in the soil by their roots. They are exposed to various biotic and abiotic stresses caused by pathogens or pests and adverse environmental conditions. To survive in biotic stresses, plants have evolved an array of many sophisticated immune responses which protect plant cells from the challenges they confront. The plant microbiome plays roles in plant health and productivity and it has been defined as a characteristic microbial community occupying a reasonably well-defined habitat. Plants live in association with diverse microbial consortia and it is referred to as the plant's microbiota which live both inside and outside of plant tissues and play important roles in the ecology and physiology of plant. Plant microbiomes are shaped by two factors-One is related to the plant itself and other one is related to the plant's environment. The study of the association of plants with microorganisms is showed by microbes which help in nitrogen and phosphorus uptake and arbuscular mycorrhizal (AM) and legume-rhizobial symbioses are the most notable examples which greatly influence the ability of roots to uptake various

nutrients from the soil. The association of AM fungi with plants has been known since 1842 and over 80% of land plants are found associated with them. *Arabidopsis thaliana* is used as a model plant in the plant microbiome studies and many others as barley, corn, rice, soybean and wheat.

Rhizosphere microbiome

The rhizosphere (1-10 mm) of soil surrounding the roots which is under the influence of the plant through its deposition of root exudates, mucilage and dead plant cells. The living of many microorganisms is specialized in rhizosphere including bacteria, fungi, oomycetes, nematodes, algae, protozoa, viruses and archea and the most frequent bacteria are within *Acidobacteria*, *Proteobacteria*, *Planctomycetes*, *Actinobacteria*, *Bacteroidetes* and *Firmicutes*. The phylum *Actinobacteria* includes members that are plant pathogens, nitrogen-fixing symbionts and fungal antagonists, as well as decomposers but the *Actinobacteria Corynebacterium* has been used as a foliar-applied plant growth promoter. The environmental elements affect plant physiology and indirectly influence microbiome composition. The species richness is also high

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in phyllosphere which is dominated by bacteria. The *alphaproteobacteria*, *gammaproteobacteria* and *Proteobacteria* are metabolically diverse and help in many processes like nitrogen fixation and nitrification. The Fungal and bacterial communities are highly variable in the phyllosphere of temperate regions than in tropical regions. The fungal community population which is present on the leaf surfaces of plants is up to 10⁷ microbes per square centimetre. The bacterial population on a global scale is estimated to be 10²⁶ cells.

Role of Phyllosphere Microorganisms in Plant Nutrient Acquisition

The presence of many nitrogen-fixing bacteria in phyllosphere microbiome plays very important role in providing nutrients to the host plant. In temperate environments, Nitrogen fixation typically occurs in the interior tissue of the leaf rather than on the leaf surface which allows nitrogenous end products to diffuse freely into plant cells. In tropical environments, Nitrogen fixation occurs in the phyllosphere because higher moisture availability at the leaf surface allow nitrogen-fixing bacteria to be active.

The Influence of the Phyllosphere Microbiome on Host Stress Tolerance: Plant growth-promoting (PGPR) bacteria are those that promote plant stress response and stimulate growth and many root-associated microorganisms can increased drought resistance to the overlying plant. Biofilms in the phyllosphere may be even resistant to desiccation than those found in water. For eg., *Pseudomonas*

putida biofilms grown in air retained their morphology better after drying than biofilms grown in liquid medium and the species of *Pseudomonas* are often dominant constituents of the phyllosphere which suggest that naturally occurring biofilms may limit the loss of water and exposure to UV radiation. The microorganisms of phyllosphere may provide UV protection to the plant host through EPS (extracellular polymeric substances) production and UV-absorbing pigmentation. The hormonal growth stimulation by PGPR and production of EPS that adheres soil to roots and help in increasing salt tolerance. Drought can increase the richness and diversity of nitrogen-fixing members of the phyllosphere which suggests a potential role of the phyllosphere microbiome in reducing nitrogen limitation triggered by drought. Wheat plants containing fungal endophytes show better yield and seed germination success when stressed by heat than non-inoculated plants. Several species of phyllosphere bacteria such as *Pantoea agglomerans* and *Pseudomonas syringae* possess cell surface protein complexes that can raise the temperature at which ice crystals form. This ice nucleation activity (INA) is generated by bacterial cell wall proteins, which have a structure resembling that of an ice crystal. When supercooled water droplets contact these proteins, they can spontaneously freeze and plants treated with *P. syringae* or *P. agglomerans* become coated with frost.

Role of the Phyllosphere Microbiome in Mediating Plant-Pathogen Interactions: Pathogens can enter the leaves of plants through a variety of

entry points such as Stomata Wounds and Hydathodes. The phyllosphere microorganisms involves interactions between the host plant and the potential pathogen for the biological control of the pathogens. Biological control can be accomplished through the induction of a plant immune response by non-pathogenic microorganisms, direct competition between non-pathogenic microorganisms and pathogens or through the production of many antibiotics. Type III secretion systems are widespread among pathogenic bacteria and flagellar molecules, β -glucans, chitin fragments, and ergosterol can also act as signals to the plant to mount its defences. Bacteria promotes the expression of degradative enzymes such as chitinase, β -1,3-glucanase and peroxidase activity by the host plant which can reduce fungal infections, suggesting another mechanism by which microorganisms can stimulate the plant to resist pathogens.

Endosphere microbiome

It consists of the microorganisms, such as endophytes, penetrate and occupy the plant internal tissues which includes the endophytic fungi, bacteria and to some degree archaea. These endophytic microbes interact with their host and provide obvious benefits to plants. The diversity of the endophytic community is lower than the diversity of the microbial community outside the plant. The identity and diversity of the endophytic microbiome of above and below ground tissues may also differ within the plant.

Currency of the Microbiome: Exudates

Exudates in the soil rhizosphere are defined here as those chemicals released from plants or from microbes. Through exudates, plants are able to communicate with microorganisms to elicit assistance in environmental acclimation to alleviate stresses, such as pathogen attack, drought-limiting nutrient acquisition, and metal toxicity. Microbes benefit from plant exudates by using them as a resource and through the exudate currency, the plant microbiome serves as an extension of the plant genome. The age and developmental stage of the plant influence exudation and subsequently the microbes proliferating around roots. *Arabidopsis* plants during the early and late stage of their development can influence the abundance of Actinobacteria, Bacteroidetes and Cyanobacteria and microbial activities.

Plant uptake and release

Plant exudates structure and constituents can be quite varied and often plant species specific which includes both high molecular weight molecules (sugars, lipids, and proteins) as well as low molecular weight signalling molecules (amino acids). These exudates also serve as an energy source for the microbiome, as in the invasive grass *Sorghum halepense*, the exudate sorgoleone is the dominant chemical exuded from root hairs and has well-known allelopathic properties. These exudates serve as a chemical currency to the plant, in turn providing a wide range of services to the plant microbiome by depositing nutrients and chemical signalling molecules. The chemical components which are released by plants often are unique to a genus or

family and can range in concentration and composition due to a wide variety of factors. Terpenoids, flavonoids, and isoflavonoids comprise many of the plant's antimicrobial defences. Isoprenoids are the most diverse group of plant metabolic compounds both structurally and functionally. Many biological molecules that are the end results of isoprenoid metabolites are essential aspects of photosynthesis and seed emergence (as gibberellic and abscisic acids). As secondary metabolites, they provide a range of benefits to plants in the form of defences from pathogens.

Microbial uptake/release

For the microbial communities, exudates are the primary means of communication within the environment. In rhizosphere, Sugars and organic amino acids are abundant and they all drive the vast microbial diversity documented for this region of the microbiome. Many chemicals as a result of microbial exudations perform essential roles in ecosystem function, in turn providing benefits such as nutrient uptake, protection from pathogens, and growth promotion to higher organisms such as plants. Microbes are responsible for biogeochemical cycling, where microbial exudates can be catalysts for the chemical transformations in soils. These transformations include those to essential plant nutrients, alkaline metals, and micronutrients. Rhizosphere microbiome helps in the transformation of nitrogen into its many oxidation states is essential for all higher organisms to survive. The Conversion of nitrogen gas into ammonium is made possible by

N_2 -fixing prokaryotes, Microbial exudates comprise much of the basis of modern antibiotics and antifungals and the excretion of antimicrobial substances is a common feature found in prokaryotic and eukaryotic microorganisms. Many microbial exudates in the rhizosphere can act directly on other microbes within the microbiome in suppressive mechanisms or can act directly on the plant to stimulate immune responses, often triggering plant exudation.

Impact on plant functions

The microbiome of plant roots plays an important role in nutrient uptake and protection from pathogens. High molecular weight compounds require active transport mechanisms to cross the plasma membrane, whereas, Low molecular weight molecules can be released through membrane diffusion. The plants are often the beneficiaries of antimicrobial exudates and it is found in the bacterial production of enzymes that degrade N-acyl-L-homoserine lactones (AHLs), commonly found among several prokaryotic genera, which inhibit quorum sensing. Raaijmakers *et al.*, (2009) observed that fluorescent pseudomonads are capable of producing the antimicrobials 2,4-diacetylphloroglucinol (2,4-DAPG) and derivatives of phenazine (Phz) which provide protection against a wide range of plant pathogens, many of which are fungal. The suppressive activity of pathogens can be induced through recruitment of microbes that secrete valuable antimicrobials and the build-up of 2,4-DAPG in the rhizosphere has been observed in many

ecosystems and is correlated with the suppression of the disease known as take-all in wheat. The low concentrations of IAA promote root growth in many plants whereas, high concentrations of IAA inhibit plant growth and cause developmental perturbations typical of plant pathogenic bacteria. The plant growth promoting bacteria (PGPB) also contain and express multiple genes important for maintaining the plant-microbial association, which have been called competent.

Ecology of the Microbiome

The aspects of the plant microbiome covered are restricted to-Rhizosphere, Rhizoplane and Internal endosymbionts

Rhizosphere and Rhizoplane: The rhizosphere region of the plant microbiome is informative about plant health, at both the individual and community level. The rhizosphere and rhizoplane microbiomes are being tapped for a wide range of services as to maximize quality, productivity, and sustainability. Some members of the microbiome stimulate induced systemic resistance in plants, marked by priming of jasmonic acid-inducible genes in leaves effectively stimulating immunity conferring resistance to a broad range of pathogens.

Epiphytes and Endophytes: The root epiphyte and endophyte communities can differ widely from those in the rhizosphere, which supports the concept of co-evolution among host plant and microbial symbionts in which the plant engages in recognition and selection of microbiomes. The colonization process that occurs between microbes and plant hosts invol-

ves exudate communication through microbe-microbe signalling interactions in addition to those between microbes and plants. The majority of known plant endophytes and epiphytes are horizontally transmitted. Horizontal transmission enables host to host transfer of endosymbionts without involvement of plant sexual reproduction. Vertical transmission of endophytes relies upon host fitness and is characterized in fungi. For example, the invasive grass *S. halepense* is a relatively newly evolved polyploid hybrid that can transmit at least some of the N_2 -fixing bacterial endophytes within the rhizomes both vertically and horizontally indicating that this successful invader might be capable of regulating potential pathogenic responses expressed by these endosymbionts.

Importance of microbiome to plant genomics

The plant microbiome influences plant root architecture. Alterations to root architecture have important implications for overall plant health. For example, border cells in roots; increased numbers of border cells conferred increased resistance to fungal pathogen infection likely due to the function of border cells in extracellular trapping of microbes that has been shown to provide a defence for the root tip.

Plant Defense Modulation of the Microbiome from a Host Gene and Phytohormone perspective

A recognized hypothesis of the plant immune system, referred to as the zigzag model, characterizes the defense response by-Pattern-triggered immunity (PTI)- First line of defense and Effector-triggered immunity (ETI)- Second line of defense.

PTI involves protein recognition receptors (PRRs) on the cell surface. The binding of microbial compounds by PRRs then elicits a signal cascade of defense responses that inhibit microbial growth. ETI is comprised of intracellular resistance (R) genes that contain nucleotide binding leucine rich repeat (NB-LRR) domains. Resistance genes code for proteins that bind microbial virulence effector proteins. Among the various phytohormones, ethylene (ET), jasmonic acid (JA), and salicylic acid (SA) have been classically characterized in some plant defense role. The role of ET in plant defense was suspected due to a measured increase in ET biosynthesis during early PTI response in *Nicotiana tabacum*. It later became evident that ET signaling was required for the expression of the receptor kinase (FLS2) which binds bacterial flagellin (flg22) in *A. thaliana* and thereby triggers the defense response. The phytohormone JA may have the capacity to shape the root microbial community by means of root exudates. *Arabidopsis thaliana* knock-out mutants *myc2* and *med25* were shown to have disrupted JA signaling pathways that result in attenuated wounding, herbivory and defense responses. The role of SA in plant defense was first described in tobacco, against tobacco mosaic virus, where supplementation of diluted aspirin induced a defense response. SA has since been described as an important component in plant defense signaling. It is believed that SA forms part of the plant's defense strategy against biotrophs, as opposed to necrotrophs which are more associated with the JA and ET pathways.

ISR is also a well-studied mechanism for plant defense, which is triggered by beneficial members of the root microbiome to a wide range of plant hosts making them resistant against various pathogenic threats.

Interactions between beneficial microorganisms and soilborne pathogens:

The growth or activity of soilborne pathogenic fungi, oomycetes, bacteria and nematodes can be inhibited by several beneficial rhizosphere microorganisms. The activity is well documented for bacteria belonging to the *Proteobacteria* (*Pseudomonas* and *Burkholderia*) and *Firmicutes* (*Bacillus* and related genera) and for fungi from the *Deuteromycetes* (e.g. *Trichoderma*, *Gliocladium* and non-pathogenic *F. oxysporum*). These beneficial microorganisms will be referred to as biocontrol microorganisms or biocontrol agents. Biocontrol microorganisms may adversely affect the population density, dynamics and metabolic activities of soilborne pathogens via mainly three types of interactions-Competition, Antagonism and Hyperparasitism. Competition can in itself be a biocontrol mechanism, often for organic compounds necessary for reactivation of propagules and subsequent proliferation and root colonisation by the pathogen. Antagonism is usually mediated by the production of secondary antimicrobial metabolites, such as, 2,4-diacetylphloroglucinol, pyrrolnitrin, pyoluteorin, phenazines, cyclic lipopeptides and hydrogen cyanide in the case of certain fluorescent pseudomonads and lytic enzymes. Antimicrobial secondary metabolites are also involved in antagonistic effects

of fungi such as *Trichoderma* and *Gliocladium*. In fungal pathogens, they may affect the electron transport chain, metalloenzymes such as copper-containing cytochrome *c* oxidases, membrane integrity or cell membrane and zoospores. Abilities of *Pseudomonas* sp. CHA0 to produce hydrogen cyanide contribute to suppression of *Thielaviopsis basicola* mediated black root rot of tobacco. Direct biocontrol effects on soilborne plant pathogens can result from hyperparasitism. This is mainly documented for *Trichoderma* and *Gliocladium*, and it affects various fungal pathogens, such as *Rhizoctonia*, *Sclerotinia*. Hyperparasitism by *Trichoderma* involves secretion of chitinases and cellulases, which release small molecules from the target pathogen and trigger chemotropism.

Source of Variability: Recent studies indicated that in several plant species the rhizosphere microbiome composition may have been affected in domesticated plants as compared to their wild relatives. For common bean, it was shown that relative abundance of Bacteroidetes was increased in wild accessions whereas *Actinobacteria* and *Proteobacteria* were enriched in modern accessions. In a study 33 strains of sunflower (*Helianthus annuus*) were used with varying degrees of domestication it was found that rhizosphere fungal communities were more strongly influenced by host genetic factors and plant breeding than bacterial communities. The domestication process affected the composition of the root-associated microbiome in various crop plant species and observed consistent enrichment of *Actinobact-*

eria and *Proteobacteria* in modern varieties in contrast to the enrichment of Bacteroidetes in their wild relatives.

Conclusion

The plant microbiome plays important roles in plant health and productivity as it is defined as "a characteristic microbial community occupying a reasonably well-defined habitat. Plants live in association with diverse microbial consortia. These microbes, referred to as the plant's microbiota which live both inside and outside the plant tissues, and play important roles in the ecology and physiology of plant. The plant microbiome is comprised of rhizosphere, phyllosphere and endosphere microbiome. The phyllosphere microbes produce growth hormones and protect the plants from different plant pathogens, whereas, rhizosphere microbes take part in nutrient cycling, produce growth hormones and give protection to different plant pathogens. Biocontrol microorganisms may also affect the population density, dynamics and metabolic activities of different pathogens by Competition, Antagonism and Hyperparasitism activities. So, with the effective management of the plant microbiome we can increase our crop yield without causing any harm to our environment and the phyllosphere, rhizosphere and endosphere microbiome help in plant growth promotion and its health.

Insect Biomimetics: From Evolution to Innovation

Priyanka S. M.

Abstract

Insect biomimetics explores the adaptation of insect structures and functions to develop innovative and sustainable technologies. Insects exhibit highly efficient evolutionary traits such as lightweight yet strong body architecture, energy-efficient locomotion, advanced sensory systems and specialized surface properties. These characteristics have inspired applications in medicine, robotics, agriculture, architecture and material science. By translating biological principles into engineering solutions, insect-inspired technologies promote energy efficiency, environmental sustainability and improved performance, offering practical solutions to modern challenges related to resource conservation and technological advancement.

Introduction

Nature has always been the greatest teacher, quietly perfecting its designs over millions of years. Among all living creatures, insects stand out as tiny engineers with extraordinary abilities. Though small in size, they display remarkable strength, efficiency, and adaptability that often surpass human-made systems. From the perfectly shaped honeycomb built by bees to the cooling systems of termite mounds and the painless bite of a mosquito, insects demonstrate solutions to complex problems in the most efficient way possible. Scientists and engineers are now turning to these natural models for inspiration through a field known as biomimetics, or biomimicry. This approach studies how insects function and applies those principles to develop innovative technologies. Insect-inspired ideas have led to lightweight building materials, advanced medical needles, water-harvesting systems, self-cleaning surfaces,

and even flying robots. By observing how insects fly, collect water, stick to surfaces, or see the world through compound eyes, researchers are designing smarter and more sustainable technologies. In a world facing challenges like climate change, water scarcity, and energy demands, learning from insects offers practical and eco-friendly solutions.

Concept of Biomimetic

Biomimetic can also be called as biomimicry. The word "Biomimetics" was coined by Otto Herbert Schmitt in 1957. The word comes from the Greek terms *bios* (life) and *mimesis* (imitation), meaning "to imitate life." Biomimetics is an interdisciplinary scientific approach that studies the structures, functions, and principles of biological systems and applies them to the design and development of innovative materials, technologies and engineering solutions to address human challenges (Nair *et al.*, 2024).

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Rather than directly copying nature, biomimetics focuses on understanding how natural designs work and adapting those ideas for practical use. Since organisms have evolved over millions of years to become efficient and sustainable, their strategies often provide smart, energy-saving, and eco-friendly solutions. In simple terms, biomimetics is innovation inspired by nature.

Why Insects for Biomimetic?

Due to various criteria insects are used as an example for biomimetic or biomimicry in various fields such as robotics, architecture, medicine and material and surface science (Gorb, 2011). Some of the conditions are as follows:

- ✓ Insects show remarkable evolutionary success due to diverse survival mechanisms and highly specialized structural adaptations developed through natural selection.
- ✓ Their lightweight chitin-protein body with hierarchical organization provides high structural efficiency, strength-to-weight ratio, and serves as an excellent model for biomimetic material design.
- ✓ Insects exhibit energy-efficient locomotion such as aerodynamically effective flapping flight and low-energy movement, which inspires micro-robotic and miniature engineering systems.
- ✓ They possess advanced sensory organs and decentralized neural control systems that function efficiently with minimal neural resources, offering models for compact sensors and autonomous technologies.

- ✓ Specialized cuticular surface properties and adaptive physiological mechanisms enable insects to survive extreme environments while inspiring innovations in surface engineering and stress-tolerant materials.

Insects Inspired Biomimetic

Mosquito-Inspired Needle: The mosquito proboscis has evolved as an extremely efficient piercing organ capable of penetrating human skin with minimal pain and tissue damage.



Based on this mechanism, bioinspired needles were developed with modified tip geometry and vibration-assisted motion. These needles significantly reduce insertion force and deviation during penetration compared to conventional needles. Such mosquito-inspired designs improve targeting accuracy and minimize patient discomfort, making them highly useful in painless injections, drug delivery systems, microsurgeries and minimally invasive medical procedures (Gidde and Hutapea, 2020).

Bee-Stinger Inspired Surgical Needle: Honeybee stingers possess backward-facing barbs that allow efficient penetration and anchorage within tissues. Mimicking this natural design, researchers developed surgical needles incorporating micro-barbed structures similar to bee stingers. These bioinspired needles reduce friction between tissue and needle surface, thereby lowering insertion force and minimizing tissue deformation. Experimental studies demonstrated improved control over needle movement and reduced deviation during surgical operat-

ions. This innovation enhances precision in medical treatments such as biopsy sampling, targeted drug injection and delicate surgical interventions where accuracy and reduced tissue damage are essential (Hutapea and Sahlabadi, 2018).

Honeycomb-Inspired Composite Structures:

Honeybees construct honeycombs using hexagonal cells that provide maximum strength while using minimum material. This naturally optimized architecture inspired engineers to develop honeycomb sandwich composite materials characterized by lightweight structure, high stiffness and excellent load-bearing capacity. These composites consist of a honeycomb core placed between thin panels, resulting in superior mechanical strength and energy absorption. Due to properties such as thermal insulation, fire resistance and durability, honeycomb-inspired materials are widely used in aircraft construction, automobile components, railway coaches, shipbuilding and aerospace engineering.



Insect-Inspired Adhesive Patch: Many insects possess specialized attachment devices that allow them to adhere to smooth, rough, wet or dry surfaces. Inspired by the adhesive structures present on the forelegs of diving beetles, scientists developed bioadhesive patches capable of strong multidirectional adhesion. These patches utilize microcavities and wrinkle-like surface structures that combine suction and capillary forces to maintain attachment even under moist conditions. Such insect-inspired

adhesive systems are particularly useful in biomedical applications, including electrocardiogram (ECG) monitoring devices, wearable sensors and skin-mounted medical instruments.

Insect Cuticle Inspired Composite Bioplastics:

The insect cuticle is a natural composite material composed mainly of chitin fibers embedded in a protein matrix, providing exceptional toughness, flexibility and protection. Inspired by this biological structure, researchers developed composite bioplastics incorporating chitosan and structural proteins similar to insect cuticular components. These biomimetic materials exhibit enhanced strength, elasticity and stretch-strengthening behavior compared to conventional plastics. Additionally, they are sustainable and biodegradable, making them suitable for applications in medical implants, bioengineering materials and environmentally friendly packaging industries.

Butterfly Wing Inspired Structural Colour Technology:

Many butterflies exhibit brilliant coloration not due to pigments but because of nanoscale surface structures that manipulate light through interference and reflection. Mimicking these structural color mechanisms, scientists developed paints and coatings that produce color without dyes or chemical pigments. These biomimetic coatings reduce toxic chemicals such as volatile organic compounds and eliminate harmful additives used in conventional paints. Applications extend to cosmetics, electronics, packaging materials and environmentally sustainable coating industries, demonstrating how insect

photonic structures can revolutionize material science.

Dung Beetle Inspired Mould Board Plough: Soil-burrowing insects like dung beetles possess non-smooth body surfaces containing convex and concave structures that reduce soil adhesion and friction. Engineers applied this concept to agricultural machinery by designing mould board ploughs with biomimetic surface patterns. These modified plough surfaces significantly decrease sliding resistance and prevent soil sticking during tillage operations. As a result, energy consumption during ploughing is reduced, improving agricultural efficiency and machinery performance.



Desert Beetle Inspired Dew Harvesting System: Desert beetles living in arid regions collect water from fog using specialized body surfaces composed of hydrophilic spots surrounded by hydrophobic regions. Water droplets condense on hydrophilic areas and roll toward the mouth due to gravity. This natural water collection mechanism inspired artificial fog-harvesting systems capable of collecting atmospheric moisture efficiently. Such biomimetic devices are especially valuable in drought-prone and desert regions for sustainable water harvesting and supply systems.



Conclusion

Insect-inspired biomimetics highlights how evolutionary adaptations of insects provide efficient

solutions for modern technological challenges. The lightweight structures, energy-efficient movement, advanced sensory systems, and specialized surface properties of insects have inspired innovations in medicine, materials science, robotics, agriculture, and engineering. These biological models contribute to the development of sustainable, high-performance and eco-friendly technologies such as micro-robots, smart sensors, lightweight materials, and water-harvesting systems. By integrating natural design principles with modern engineering, insect biomimetics offers promising approaches for future technological advancement and sustainable development.

References

- Floreano, D., Pericet-Camara, R., Viollet, S., Ruffier, F., Brückner, A., Leitel, R., Buss, W., Menouni, M., Expert, F., Juston, R., & Dobrzynski, M. K. (2013). Miniature curved artificial compound eyes. *Proceedings of the National Academy of Sciences*, 110(23): 9267-9272.
- Gidde, S. T. R. and Hutapea, P. (2020). Design and experimental evaluation of mosquito-inspired needle structure in soft materials. *Proceedings of the ASME International Mechanical Engineering Congress and Exposition*, 84-122.
- Gorb, S. N. (2011). Insect-inspired technologies: Insects as a source for biomimetics. In A. Vilcinskas (Ed.), *Insect Biotechnology*. pp. 241-264.

- Hutapea, P. and Sahlabadi, M. (2018). Tissue deformation and insertion force of bee-stinger inspired surgical needles. *Journal of Medical Devices*, 12(3): 031008.
- Nair, J. S., Kumar, S. T. and Anitha, N. (2024). Biomimetics: Insect - inspired technologies. *Journal of Tropical Agriculture*, 62(1): 41-50.



Role of Plant Breeding in Achieving Global Food Security

Sure Naveen

Abstract

Global food security remains one of the most pressing challenges of the 21st century, driven by rapid population growth, climate change, declining arable land, and evolving pest and disease pressures. Plant breeding has emerged as a cornerstone strategy to enhance agricultural productivity, resilience, and nutritional quality of crops. This review explores the role of conventional and modern plant breeding approaches in ensuring sustainable food production. It highlights the evolution from traditional selection methods to advanced genomic tools, including marker-assisted selection, genomic selection, and gene editing technologies. The integration of climate-resilient traits, biofortification, and stress tolerance in crop improvement programs has significantly contributed to improving yield stability and nutritional security. Furthermore, the review discusses challenges such as genetic erosion, regulatory constraints, and socio-economic barriers, while emphasizing the need for interdisciplinary collaboration and policy support. Overall, plant breeding remains indispensable in achieving global food security and sustainable agricultural development.

Introduction

Food security, defined as access to sufficient, safe, and nutritious food, is increasingly threatened by global challenges such as climate variability, population expansion, and resource limitations. According to global estimates, the world population is expected to exceed 9 billion by 2050, necessitating a substantial increase in food production. Plant breeding plays a crucial role in addressing these challenges by developing high-yielding, stress-tolerant, and nutritionally enriched crop varieties. Historically, crop improvement relied on natural selection and farmer-led practices, but scientific breeding has transformed agriculture through systematic selection and hybridization. Modern plant breeding integrates genetics, biotechnology, and data

science, enabling precise and efficient crop improvement. This review examines the contribution of plant breeding to food security, focusing on technological advancements, applications, and future prospects.

Importance of Plant Breeding in Food Security



Plant breeding contributes to food security through multiple pathways:

- ✓ Increasing crop yield potential

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- ✓ Enhancing resistance to pests and diseases
- ✓ Improving tolerance to abiotic stresses (drought, salinity, heat)
- ✓ Enhancing nutritional quality
- ✓ Ensuring yield stability under changing climates

Conventional Plant Breeding Approaches

Conventional breeding methods laid the foundation for modern crop improvement.

Selection: Selection involves choosing superior plants based on desirable traits such as yield, disease resistance, and adaptability.

Hybridization: Hybridization combines traits from different parent lines to produce improved offspring. This approach led to the development of high-yielding varieties during the Green Revolution.

Mutation Breeding: Induced mutations using chemicals or radiation have generated beneficial traits, including disease resistance and improved quality.

Table 1: Conventional Breeding Methods and their Contributions

Method	Key Contribution	Example Outcome
Selection	Improved local adaptability	Landrace improvement
Hybridization	Increased yield potential	Hybrid maize
Mutation breeding	Novel trait development	Disease-resistant varieties

Modern Plant Breeding Technologies

Advances in molecular biology and genomics have revolutionized plant breeding.

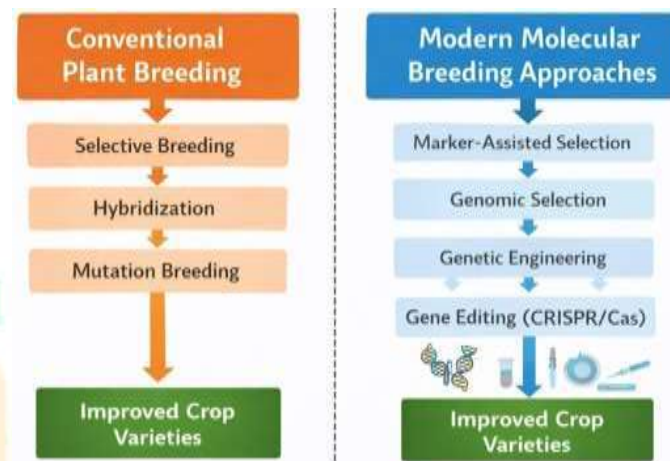
Marker-Assisted Selection (MAS): MAS uses molecular markers linked to desirable traits, enabling breeders to select plants at early stages without waiting for full growth.

Genomic Selection (GS): Genomic selection uses genome-wide markers to predict breeding values,

accelerating the development of improved varieties.

Genetic Engineering: Genetic engineering introduces specific genes into crops, conferring traits such as pest resistance and herbicide tolerance.

Gene Editing (CRISPR/Cas Systems): Gene editing allows precise modification of plant genomes, enabling rapid development of improved traits without introducing foreign DNA.



Breeding for Climate Resilience

Climate change significantly impacts agricultural productivity through temperature fluctuations, water scarcity, and extreme weather events. Plant breeding addresses these challenges by developing:

- ✓ Drought-tolerant varieties
- ✓ Heat-resistant crops
- ✓ Flood-tolerant rice varieties
- ✓ Salt-tolerant crops for degraded soils

Example: Development of submergence-tolerant rice varieties has helped farmers in flood-prone regions maintain productivity.

Biofortification and Nutritional Security

Food security is not only about quantity but also quality. Micronutrient deficiencies affect billions of people worldwide.

Plant breeding contributes to nutritional security through biofortification, which enhances the nutritional content of crops.

Examples include:

- ✓ Iron-rich rice
- ✓ Zinc-enriched wheat
- ✓ Vitamin A-enriched crops

Biofortified crops provide a cost-effective solution to malnutrition, especially in developing countries.

Table 2: Examples of Biofortified Crops

Crop	Nutrient Enhanced	Benefit
Rice	Iron, Zinc	Reduces anemia
Wheat	Zinc	Improves immunity
Maize	Vitamin A	Prevents blindness

Role of Plant Breeding in Sustainable Agriculture

Sustainability is a key component of food security. Plant breeding supports sustainable agriculture by:

- ✓ Reducing dependence on chemical inputs
- ✓ Enhancing resource-use efficiency
- ✓ Promoting biodiversity conservation
- ✓ Improving soil health through resilient crop varieties

Breeding for pest resistance reduces pesticide use, while nitrogen-use-efficient crops reduce fertilizer requirements.

Challenges in Plant Breeding

Despite its advancements, plant breeding faces several challenges:

Genetic Erosion: Loss of genetic diversity limits breeding potential and adaptability.

Climate Uncertainty: Rapid and unpredictable climate changes complicate breeding targets.

Regulatory and Ethical Issues: Biotechnology-based breeding methods face regulatory hurdles and public concerns.

Limited Resources: Developing countries often lack infrastructure and funding for advanced breeding programs.

Future Perspectives

The future of plant breeding lies in integrating multiple disciplines:

- ✓ Artificial Intelligence (AI) in breeding
- ✓ Big data and predictive analytics
- ✓ Speed breeding techniques
- ✓ Participatory breeding involving farmers

Combining traditional knowledge with modern technologies can accelerate the development of climate-resilient and nutrient-rich crops.



Conclusion

Plant breeding is a fundamental pillar in achieving global food security. From traditional selection methods to advanced genomic technologies, it has significantly enhanced agricultural productivity, resilience, and nutritional quality. As global challenges intensify, the role of plant breeding becomes even more critical. Addressing existing

challenges through innovation, policy support, and international collaboration will ensure sustainable food production for future generations. Continued investment in research and development is essential to harness the full potential of plant breeding in securing global food systems.

References

- FAO. (2021). The state of food security and nutrition in the world. Food and Agriculture Organization.
- Tester, M. and Langridge, P. (2010). Breeding technologies to increase crop production in a changing world. *Science*, 327(5967): 818-822.
- Moose, S. P. and Mumm, R. H. (2008). Molecular plant breeding as the foundation for 21st century crop improvement. *Plant Physiology*, 147(3): 969-977.
- Varshney, R. K., Ribaut, J. M., Buckler, E. S., Tuberosa, R., Rafalski, J. A. and Langridge, P. (2012). Can genomics boost productivity of orphan crops? *Nature Biotechnology*, 30(12): 1172-1176.
- Godfray, H. C. J., *et al.* (2010). Food security: The challenge of feeding 9 billion people. *Science*, 327(5967): 812-818.
- Zhu, C., Naqvi, S., Gomez-Galera, S., Pelacho, A. M., Capell, T. and Christou, P. (2007). Transgenic strategies for the nutritional enhancement of plants. *Trends in Plant Science*, 12(12): 548-555.
- Hickey, J. M., *et al.* (2019). Breeding crops to feed 10 billion. *Nature Biotechnology*, 37(7): 744-754.
- Dwivedi, S. L., *et al.* (2017). Breeding for abiotic stress tolerance in crops. *Plant Breeding Reviews*, 41: 1-71.

Vermicompost: A Powerful Crop Nutrient

V. K. Bagul, S. G. Thakare and K. P. Bhoje

Introduction

Current agriculture driven by the adoption of inorganic fertilizers that helps to increase crop yield but deteriorates the soil and environment health. The excessive use of synthetic inputs that's leads to rapid decomposition of soil organic matter, disturbed soil structure, reducing particle aggregation, and diminishing fertilizer use efficiency through nutrient fixation and leaching. (Wang *et al.*, 2010). The disturbance of natural decomposer within agro-ecosystems poses a threat to food security. Therefore, the urgent need for organic fertilizers to achieve sustainable agriculture serves as an alternative to traditional methods that depend on synthetic inputs. (Singh *et al.*, 2011). Among organic fertilizers, Vermicompost is distinctive fertilizers for potential to significantly boost crop growth. It acts as a superior soil conditioner, enhancing soil structure, aeration, and water-holding capacity while releasing essential nutrients like Nitrogen, Phosphorus, and Potassium. Vermicomposting is an economically feasible and eco-friendly method of converting huge quantities of organic waste into high-quality organic fertilizer through controlled bio-oxidation involving earthworms and associated microbes.

Vermicompost reduces soil pH, increases microbial activity, increases porosity and water retention capacity and improves overall soil health. These improvements lead to better germination, growth, development and yield of crops. This article review that the methods of production and importance of vermicompost in enhancing the performance of crops.

What is Vermicompost?

Vermicompost is the product of the decomposition process using various species of earthworms, to create a mixture of decomposing agricultural or food waste.

Terminology

- ✓ Vermicomposting it is a process of conversion of biodegradable matter by earthworm into high-quality organic fertilizer or vermicast (Gajlakshmi and Abbasi, 2003).
- ✓ Vermitechnology is a combination of vermiculture and vermicomposting.
- ✓ Vermiculture: The rearing of worms for the purpose of vermicomposting is called vermiculture.
- ✓ Vermicast (also called worm castings, worm humus, worm manure or worm faeces) is the

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end-product of the breakdown of organic matter by earthworms.

- ✓ Vermiwash: Vermicompost contains water-soluble nutrients which may be extracted as vermiwash. Vermiwash contains beneficial microorganisms, enzymes and nutrients such as nitrogen, phosphorus, potassium and trace minerals, making it an excellent organic fertilizer for plants.

Earthworm: Friend of farmers

Earthworms are soil dwelling invertebrates belonging to phylum Annelida and class Oligochaeta. Other common name for earthworms is dew-worm, rain worm, night crawler, and angleworm (due to its use as angling hook baits) (Kumar and Ali, 2025). Earthworms are “Ecological Engineers” as they involve in soil building, soil turnover, increasing soil aeration, increasing porosity of soil, water holding capacity and maintenance of soil fertility. They are also known as “Natural Ploughman” and “Farmer’s Friend” due to their crucial roles in soil ecosystem. Earthworms are commonly found in moist, nutrient-rich soil, eating a variety of organic matters which include detritus living protozoa, rotifers, nematodes, bacteria, fungi and other microorganisms.

Role of Earthworm

- ✓ Earthworms act as the soil conditioners by improving the physical, chemical and biological properties of the soil. They help in soil development viz., soil fertility and aeration, water holding capacity and formation of the productive

soil.

- ✓ Earthworms contribute in the soil forming process by five ways such as by altering soil pH, by causing physical and chemical decomposition of organic matter, by humus formation, by improving soil texture and by enriching the soil with nutrients and minerals.
- ✓ Vermicompost obtained by decomposition of organic waste through earthworm’s gut is quite different from its parental waste material and popularly known as black gold (Lim *et al.*, 2015; Patangray, 2014). It boosted the practices of organic farming all over the world.
- ✓ Earthworms also enhance the physical properties of soil such as hydraulic conductivity, porosity, decrease bulk density, infiltrability, aggregate stability etc. (Devkota *et al.*, 2014).
- ✓ Earthworms improve nutrient availability by consuming organic waste that have various carbon and nitrogen ratios (Patnaik and Dash 1990). Activities of earthworms also help in enhancing beneficial soil microbes.

Species of earthworm used for vermicomposting

The main criteria for selection are:

- ✓ Must be easy to culture
- ✓ High rate of vermicast output per worm
- ✓ High affinity for the organic content to be vermicomposted.

***Eisenia fetida* and *E. andrei*:** Often called red wigglers or tiger worms, these are the most utilized species worldwide due to their high tolerance for temperature variations and rapid waste consumption.

***Eudrilus eugeniae* (African Nightcrawler):** Highly popular in tropical research, they are fast-growing, large, and efficient, though they prefer warmer temperatures.

***Perionyx excavatus* (Indian Blue Worm):** Known for rapid reproduction and surface-dwelling, often used for tropical waste management.

***Dendrobaena veneta* / *Eisenia hortensis*:** Frequently used in research, especially when large biomass production is desired



Fig 1: Most popular earthworm species commonly used to prepare vermicompost

Methods of composting

Material required for preparation of vermicompost

Composting requires all biodegradable waste, including cow dung, crop residues, weed biomass, vegetable trash, leaf litter, home waste, hotel waste, waste from agro-industries, and biodegradable components of rural and urban waste. Different types of methods used for prepare vermicompost but pit method of vermicomposting is adopted popularly because it is suitable for large-scale production and effectively controls odors.

Pit/Bin Method: In this method, the organic matter is collected in cemented pits. Pit should be any convenient size. Farmers can build vermicompost unit, could be of thatched roof supported by bamboo rafters and purlins, wooden or steel trusses and stone or RCC pillars. Locally available roofing material or

HDPE sheet may also be used in roofing to keep the capital investment at reasonably lower level. Permanent sheds are constructed using cement bricks or bricks or using



Kadapa slabs. The size of the shed is chosen in such a way that wetting of beds due to rain on a windy day should be prevented. While designing the sheds adequate room/pathways have to be left around the beds for easy movement of the labors attending to the filling and harvesting the beds.

Procedure:

Before filling the tank, cow dung slurry should be sprinkled on the floor and the wall.

First layer: Decomposable plant material (Crop residues, leafy material, paddy straw, Groundnut husk, Greengram, blackgram husk etc.) are spread evenly in layers to a thickness of 6 inches (100 4100 kg)

Second layer: Cow dung or bio gas slurry @ 4-5 kg in 100-125 lt of water on the first layer of the residues. Likewise total tank is filled in this way layer by layer and it is filled till the material is 1.5 ft above ground/brick level. Whole tank is filled within 1 or 2 days. 10-12 layers are required for for filling the tank to its capacity.

- ✓ After adding all the bio-wastes, release the earthworm species over the mixture and cover the compost mixture with dry straw or gunny bags.
- ✓ Sprinkle water as & when necessary to maintain

50-70% moisture content.

- ✓ Provide shade over the compost mixture to protect from rain water & direct sunlight. Cover the tank with a thatch roof to prevent the entry of ants, lizards, mouse, snakes, etc.
- ✓ Stop sprinkling of water when 80-90 % biowaste is decomposed.
- ✓ Have a frequent check to avoid the compost from overheating. Maintain proper moisture and temperature.
- ✓ Maturity could be judged usually by observing the formation of granular structure (After 3 months).
- ✓ Collect the vermicompost by scrapping layer wise from the top of the tank & keep it under shade.



Fig. 3: Formation of granular structure

Harvesting compost and earthworms

- ✓ Completely decomposed raw material appears black and granular.
- ✓ All the worms spread across the pit come in closer and form balls.
- ✓ Heap the compost by removing the balls
- ✓ Material is then sieved in 2 mm sieve
- ✓ The sieved material is the vermicompost

Storing and packing of vermicompost

- ✓ The harvested vermicompost should be stored in dark, cool place.
- ✓ It should have minimum 40% moisture.

- ✓ If it is stored in an open place, periodical sprinkling of water may be done to maintain moisture level and also to maintain beneficial microbial population.

Nutrient composition of Vermicompost

S.No.	Particulars	(%)
1.	Humus	30 to 35 %
2.	Nitrogen	1.4 to 1.06 %
3.	Phosphorus	0.5 to 1.5 %
4.	Potash	0.5 to 1.0 %
5.	C : N ratio	16 %
6.	Organic carbon	09 to 14 %
7.	Sulphur	100-500 ppm
8.	Calcium	1.6 to 2.2 %
9.	Magnesium	0.3 to 0.6 %
10.	Iron	6.9 to 9.3 ppm
11.	Zinc	5.7 to 11.5 ppm
12.	pH	6.5 to 8.5

*ppm: Parts per million (Singare and Meshram, 2014)

Recommended dosage in different crops

Crop	Dosage (ha/acre/pot/plant)
Field crops	5-6 t ha ⁻¹
Fruit crops	3-5 kg plant ⁻¹
Vegetables	1-1.5 tonnes acre ⁻¹
Flowers	100-200 g pot ⁻¹
Rice	1 tonne acre ⁻¹ after transplanting
Chilli	1 tonne acre ⁻¹ last ploughing
Groundnut	0.5 tonne acre ⁻¹
Sugarcane, Cotton, Maize, Sunflower, Turmeric	1 tonne acre ⁻¹ last ploughing
Citrus, Pomegranate, Ber, Guava	2 kg tree ⁻¹ at planting time and before flowering 1-2-year-old tree
Mango, Coconut	2 kg tree ⁻¹ at planting time 5 kg tree ⁻¹ 1-5-year-old trees 10 kg tree ⁻¹ 6-9-year-old trees 0 kg tree ⁻¹ Trees older than 10 years

(CRIDA)

Advantage of Vermicompost

- ✓ Vermicompost is rich in all essential plant nutrients and neutralizes the Soil pH.
- ✓ Provides excellent effect on overall plant growth, encourages the growth of new shoots/leaves and improves the quality and shelf life of the produce.
- ✓ It is free flowing, easy to apply, handle and store

and does not have any bad odour.

- ✓ It improves soil structure, texture, aeration, water holding capacity, prevent soil erosion and maintain soil temperature.
- ✓ It is rich in beneficial micro-flora such N-fixers, Phosphorus solubilizers, cellulose decomposing micro-flora, etc., and free from pathogens, toxic elements, weed seeds, etc.
- ✓ It neutralizes soil pH and it also prevents nutrient losses and increases the use efficiency of chemical fertilizers
- ✓ It minimizes the incidence of pest and diseases.
- ✓ It enhances the decomposition of organic matter in soil and contains valuable vitamins, enzymes and hormones like auxins, gibberellins etc.
- ✓ It contains earthworm cocoons and increases the population and activity of earthworm in the soil.
- ✓ Economically efficient.

Conclusion

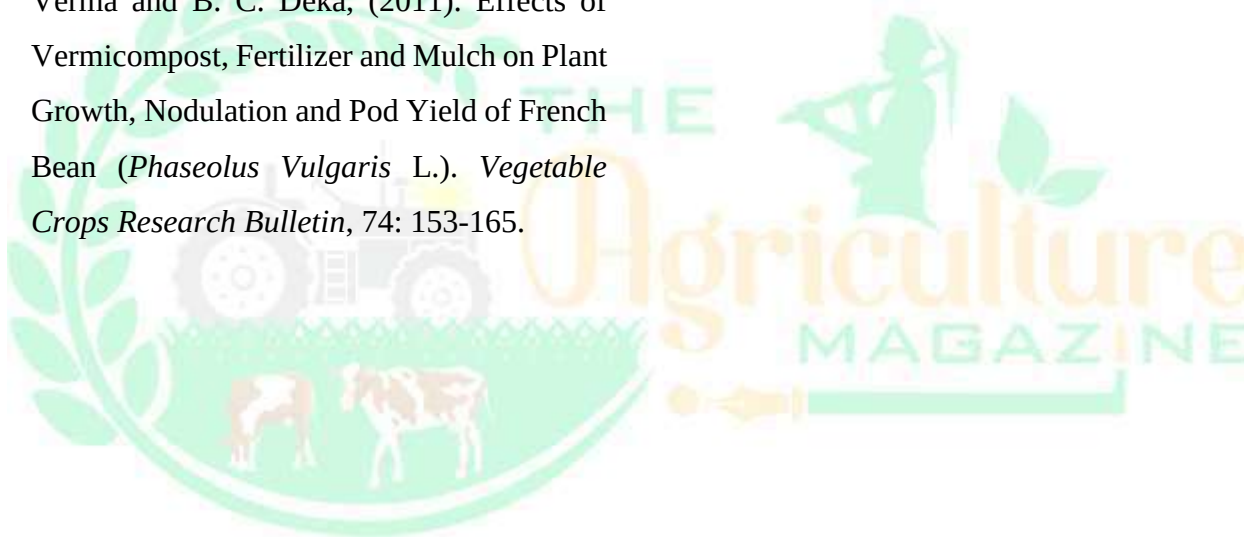
Vermicompost is nutrient rich organic fertilizer from natural sources, which releases nutrients in the soil and improves quality of the plants with maintains physical and biological properties of soil. However, vermicompost prepared from locally available materials such as mixture of all straws were analyzed for their nutrient evaluation. Therefore, it provides organic fertilizer, a viable alternative to chemical fertilizers, which can have hazardous effects on both crops as well as human beings. It is considered a natural fertilizer as it is produced using natural processes and contains a variety of essential nutrients, micronutrients, beneficial soil microbes,

plant growth hormones and enzymes. The use of vermicompost can resolve the immediate problem of declining soil fertility, which is a major challenge in modern agriculture.

References

- Information leaflet by Central Research Institute for Dryland Agriculture (CRIDA). P.O. Saidabad, Hyderabad-500 059.
- Sinagare, P. B. and Meshram, N. A. (2014). Importance of Vermicompost. *Krushibhushan Magazine*, 2: 61-63.
- Lim, S., Wu, T. Y., Lim, P. N. and Shak, K. P. Y. (2015). The use of vermicompost in organic farming: overview, effects on soil and economics. *Journal of Science, Food and Agriculture*, 95(6): 1143-1156.
- Gajalakshmi, S. and Abbasi, S. A. (2003). High rate of vermicomposting system for recycling paper waste. *Indian Journal of Biotechnology*, 2: 613-615.
- Patnaik, H. K. and Dash, M. C. (1990). Toxicity of monocrotophos and fenitrothion to four common Indian earthworm species. *Poll Residue*, 9: 95-99.
- Devkota, D., Dhakal, S. C., Dhakal, D., Dhakal, D. and Ojha, R. B. (2014). Economics of Production and Marketing of Vermicompost in Chitwan, Nepal. *International Journal of Agriculture and Soil Science*, 2(7): 112-117.
- Patangray, A. J. (2014). Vermicompost: beneficial tool for sustainable farming. *Asian Journal of Multidisciplinary Studies*, 2(8): 254-257.

- Kumar, J. and Ali, A. (2025). A Review on the Growing Threats to Earthworm (The Farmer's Friend). *Biological Forum - An International Journal*, 17(1): 82-86.
- Wang D., Shi Q., Wang X., Wei M., Hu J., Liu, J. and Yang F. (2010). Influence of cow manure vermicompost on the growth, metabolite contents and antioxidant activities of Chinese cabbage (*Brassica campestris* ssp. *chinensis*) *Biology and Fertility of Soils*, 46: 689-696.
- Singh, B. K., K. A. Pathak, A. K. Verma, V. K. Verma and B. C. Deka, (2011). Effects of Vermicompost, Fertilizer and Mulch on Plant Growth, Nodulation and Pod Yield of French Bean (*Phaseolus Vulgaris* L.). *Vegetable Crops Research Bulletin*, 74: 153-165.



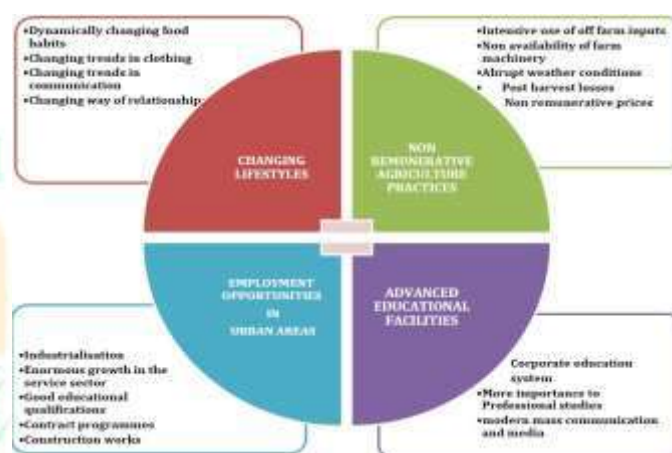
Family Farming: A Captivating Tactic for Agroecology

Neelima P., Sravanthi D., Shireesha K. and Hemantha Kumar J.

Introduction

In the ancient India every family in a village was an individual unit of production by cultivating staple food crops, managing livestock and was self-sufficient with nutritious foods required for family members and the surplus was marketed in the local markets. The joint family culture in those days helped them to practice agriculture along with the cattle by large section of the rural people. On the other side the sheep and goat was reared by the resource poor people in the villages. Diversified practices viz., application of farm yard manure and sheep and goat manure to the crops helped in the enrichment of soil health, pest and disease control by natural agents, recycling the agriculture waste as feed to the cattle, dairy products from the cattle, protein rich source products from backyard poultry, vegetables and fruits from nutritional gardening in the backyards created the ambient atmosphere of a family in the villages in the olden days. This ambient atmosphere helped to maintain the not only the agro ecology system but also the traditions and culture of the gigantic nation. The United Nations' Food and Agriculture Organization (FAO) defined the family farm as "An agricultural holding which is managed and operated by a household and where farm labour is largely supplied by that household". Further, they said that the Family farms are by far the most comm-

on type of farm encompassing a wide range of agricultural holdings from small, semi-subsistence farms with only family workers and farms which have to rely on other gainful activities for a diversified source of income, through to much larger, more productive farms which nevertheless are mostly managed by family members (Anonymous, 2019)



Reasons for Mobilization from rural to urban areas

The changing lifestyles and the non remunerative agriculture, advanced education and employment facilities led to drastic changes in the farming patterns in the villages and broken down the joint family system into nuclear families. This gave rise to split up of large land holdings into small and marginal land holdings which resulted in more number of small and marginal farmers in the country. Due to increased rate of pollution, uncertain climatic conditions agriculture ecology has been disturbed completely leading to less profits and poor income

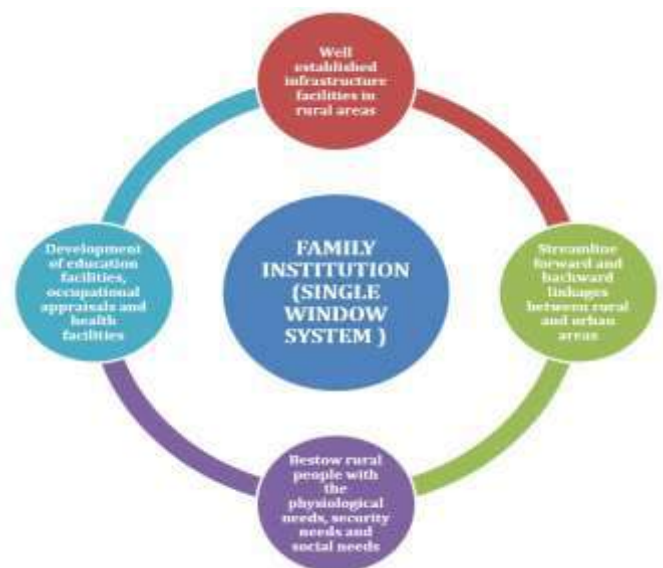
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levels of farming community. The United Nations declared 2019-2028 as the Decade of Family farming. This has done with a view that the family farming aims to throw new light on what it means to be a family farmer in a rapidly changing world and highlights more than ever before the important role they play in eradicating hunger and shaping our future towards food security. Family farming offers an unique opportunity to ensure food security, improve livelihoods, better manage natural resources, protect the environment and achieve sustainable development, particularly in rural areas. The communities of the family farming particularly emphasizing on the health of the soil thereby maintaining the soil fertility, family farmers are considering as the agents of change we need to achieve for Zero Hunger, a more balanced and resilient planet, and the Sustainable Development Goals. Family farms occupy around 70-80% of the farm land worldwide and producing more than 80 % of the food in the world and 90% of the fishery is operated by family farms.

The resource poor farmers migrated from rural areas to urban areas in search of hectic and laborious employment opportunities in the urban areas leaving the villages abandoned. Thus disintegrating the family farming system. If this situation is continued then there would be no human being in the villages in the coming decades. As quoted by Mahatma Gandhi “The future of the nation lies in its villages”, in order to see the future it is our responsibility to protect our villages from disintegr-

ation which is possible through mobilizing the integrated farming system approach by each family residing in the villages. The policy makers must come forward to implement the innovative strategies to regain the village structure and agro ecology prevailed in those days. Different capacity building activities must be taken up to upgrade the stakeholders involved in the entire farming system through a systematic approach.



Forward and backward linkages between rural and urban areas

The family institution at village level must become the single window system for all the food products required by the human beings of all the ages. In order to rejuvenate the family farming system primarily the infrastructure facilities at the villages must be improved to a large extent because even today many hamlets and village gram panchayats don't have all weathered road, shortage of electricity, lack of proper communication facilities, poor access to different multimedia and social networking even in this so called digital world.

Secondarily the linkages between the rural and urban amenities must be enhanced and interdependence of both rural and urban areas must be designed sophisticatedly. The forward and backward linkages between rural and urban areas must be streamlined so that the people living in both areas get benefits. If the people in the rural areas are bestowed with the physiological needs, security needs and social needs that are essential for them, then they never try to migrate to the urban areas. UN decade of family farming 2019-2028, has highlighted many key issues viz., Zero Hunger, a more balanced and resilient planet, and achieving the Sustainable Development Goals (Anonymous, 2019). Another advantage with the family farming is that, they can blend the traditional agricultural practices with technical know-how there by can promote the food systems with are more resilient to climate change, which is one of the burning issues in the present scenario.

Conclusion

In this line, keeping in view of importance of family farming, the local self-government personnel, department officials must contribute to the development of education facilities, occupational appraisals and health facilities available at present to the satisfactory level of rural people. The smart world and digital world can boost up the agro ecology system optimistically in the villages by using the advanced technologies to fasten the rejuvenation of family farming system. Further, youth is the future of the family farming, because young farmers are the Bridgestone between traditional local knowledge and

innovative ideas. In this context, we strongly recommend that family farming is the only system which protects the indigenous technology and can make food systems more sustainable.

References

- Anonymous. (2019). <https://www.fao.org/family-farming-decade/home/en/>
- Anonymous. (2019). https://ec.europa.eu/eurostat/statisticsexplained/index.php?title=Agriculture_statistics_-_family_farming_in_the_EU

Nature's Silent Workforce: Protecting Insect Pollinators and their Ecosystem Services

Nagendra Kumar

Abstract

Insect pollinators constitute a vital yet often overlooked component of terrestrial ecosystems and global agricultural productivity. These organisms, including bees, butterflies, flies, beetles, and moths, facilitate the reproduction of flowering plants through pollination, thereby sustaining biodiversity and ensuring food security. Recent evidence indicates alarming declines in pollinator populations due to anthropogenic pressures such as habitat destruction, pesticide exposure, climate change, and invasive species. This review synthesizes current knowledge on the ecological and economic significance of insect pollinators, the mechanisms underlying their decline, and sustainable strategies for their conservation. Emphasis is placed on ecosystem services, plant-pollinator interactions, agricultural dependency, and integrated management approaches to safeguard pollinator diversity. The study underscores the urgency of adopting multi-disciplinary conservation frameworks to maintain ecological balance and ensure long-term agricultural sustainability.

Introduction

Insect pollinators represent one of the most indispensable biological assets of terrestrial ecosystems, functioning as key mediators of plant reproduction and ecosystem resilience. The process of pollination underpins the reproductive success of angiosperms, enabling genetic recombination and seed production. While abiotic pollination contributes to certain crops such as cereals, the majority of flowering plants rely on biotic pollination, predominantly carried out by insects. The global agricultural landscape is intricately dependent on insect pollinators, with approximately three-quarters of major crop species showing varying degrees of pollinator dependence. Crops such as apple, almond,

mustard, sunflower, cucurbits, and coffee exhibit substantial yield and quality improvements through effective pollination. In developing countries, including India, pollination services are directly linked to smallholder livelihoods and nutritional security, particularly in horticulture-based farming systems.

Beyond agriculture, pollinators contribute significantly to maintaining ecological integrity by supporting plant diversity, which in turn sustains herbivores, predators, and decomposers. Thus, insect pollinators serve as a foundational pillar in sustaining both natural ecosystems and human food systems.

Diversity and Functional Ecology of Insect Pollinators

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The diversity of insect pollinators is immense, spanning multiple orders including Hymenoptera, Lepidoptera, Diptera, Coleoptera, and even certain Hemiptera. Among these, bees are the most specialized and efficient pollinators due to their morphological adaptations such as branched hairs, pollen baskets (corbiculae), and sophisticated foraging behaviour. However, non-bee pollinators such as hoverflies, beetles, and moths contribute significantly to pollination networks, especially in ecosystems where bees are less abundant. For instance, flies are dominant pollinators in high-altitude and cold environments, while beetles are among the earliest pollinators from an evolutionary perspective. Functional diversity among pollinators enhances ecosystem resilience through complementary roles. Some species specialize in specific plant taxa, while others act as generalists, ensuring pollination across diverse plant communities. Temporal and spatial variation in pollinator activity further stabilizes pollination services.

Mechanisms and Dynamics of Pollination

Pollination involves complex behavioural and ecological interactions between plants and pollinators. The process is influenced by floral traits such as colour, morphology, nectar composition, and volatile compounds that attract specific pollinators. Pollinators, in turn, exhibit learning behaviour, memory, and floral constancy, which enhance pollination efficiency. Two major types of pollination are recognized: self-pollination and cross-pollination. Insect-mediated cross-pollination

is particularly important as it promotes genetic diversity and enhances plant adaptability to environmental stressors. Pollinator foraging patterns, including visitation frequency and pollen transfer efficiency, directly affect reproductive success. The concept of pollination syndromes explains the association between floral traits and pollinator types, such as melittophily (bee pollination), psychophily (butterfly pollination), and phalaenophily (moth pollination). These specialized interactions highlight the co-adaptive nature of plant-pollinator relationships.

Ecosystem Services of Insect Pollinators

Agricultural Productivity and Nutritional Security: Pollinators contribute not only to yield quantity but also to crop quality attributes such as fruit size, shape, colour, and nutrient composition. Pollination enhances the concentration of essential micronutrients including vitamins, antioxidants, and minerals, thereby contributing to human health. Pollinator-dependent crops are often rich in micronutrients, and their decline can lead to nutritional deficiencies, particularly in vulnerable populations. Thus, pollinators play a hidden but critical role in addressing global malnutrition.

Biodiversity Conservation: Pollinators maintain plant diversity, which is essential for ecosystem stability and resilience. Diverse plant communities provide habitats and food resources for a wide range of organisms, thereby supporting biodiversity at multiple trophic levels.

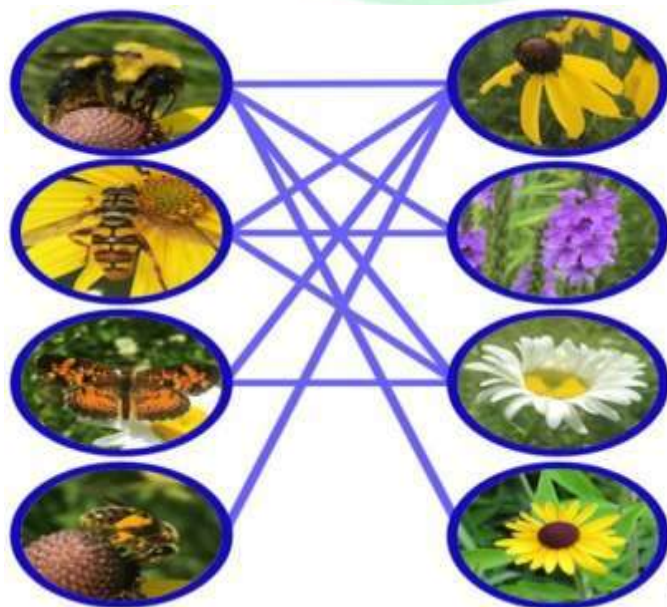
Economic Valuation of Pollination Services: The

economic value of insect pollination is immense, with global estimates ranging between 235 to 577 billion USD annually (IPBES, 2016). In India, pollination services significantly enhance the productivity of crops such as mustard, apple, and cardamom.

Ecosystem Stability and Climate Regulation: By supporting vegetation cover, pollinators indirectly contribute to carbon sequestration, soil conservation, and climate regulation. Healthy plant communities mitigate climate change impacts and enhance ecosystem resilience.

Co-Evolution and Ecological Networks

Plant-pollinator interactions are embedded within complex ecological networks characterized by mutual dependencies. These networks exhibit properties such as nestedness and modularity, which enhance stability and resilience. Coevolution has led to remarkable adaptations, such as long-tongued bees matching deep corolla tubes and orchids mimicking insect pheromones.



While specialization increases efficiency, it also increases vulnerability to environmental disturbances. Understanding these networks is crucial for predicting the impacts of pollinator loss and designing effective conservation strategies.

Drivers of Pollinator Decline

Pollinator decline is a multifactorial phenomenon driven by interacting stressors. Habitat loss remains the most significant factor, as natural ecosystems are converted into agricultural or urban landscapes. The loss of floral diversity and nesting sites severely limits pollinator survival. Pesticide exposure, particularly systemic insecticides, disrupts neural functioning, foraging behaviour, and colony health. Sublethal effects are especially concerning as they impair navigation and reproduction without causing immediate mortality.



Climate change introduces phenological mismatches between flowering plants and pollinator activity. Additionally, rising temperatures and altered precipitation patterns affect pollinator physiology and distribution. Pathogens and parasites such

as *Varroa destructor*, weaken pollinator populations, particularly managed honey bees. The spread of diseases is exacerbated by global trade and movement of pollinator species. Agricultural intensification, characterized by monocropping and excessive chemical inputs, creates hostile environments for pollinators by reducing habitat heterogeneity and food resources.

Consequences of Pollinator Decline

The decline of pollinators has profound ecological, economic, and social consequences. Reduced pollination leads to lower crop yields, poor fruit quality, and increased production costs due to reliance on artificial pollination methods. In natural ecosystems, pollinator loss results in decreased plant reproduction, leading to cascading effects on herbivores and higher trophic levels. This can ultimately destabilize entire ecosystems. From a socio-economic perspective, pollinator decline threatens food security, rural livelihoods, and global trade. The loss of pollinator-dependent crops can disproportionately affect developing countries.

Conservation Strategies and Sustainable Management

Habitat Enhancement and Landscape Management: Creating pollinator-friendly habitats through flowering strips, hedgerows, and agroforestry systems can significantly enhance pollinator abundance and diversity. Landscape-level planning is essential to ensure habitat connectivity.

Agroecological Approaches: Sustainable farming practices such as crop rotation, intercropping, and

reduced tillage promote biodiversity and provide continuous floral resources. Organic farming systems have been shown to support higher pollinator diversity.

Pesticide Risk Mitigation: Adopting Integrated Pest Management (IPM) reduces reliance on chemical pesticides. The use of biopesticides, botanical extracts, and precision application techniques minimizes harm to pollinators.

Conservation of Wild Pollinators: Efforts should extend beyond managed honey bees to include wild pollinators, which are often more efficient and resilient. Conservation strategies must focus on protecting nesting habitats and reducing disturbances.

Policy and Institutional Frameworks: International initiatives such as the IPBES pollinator assessment and national biodiversity strategies play a critical role in conservation. Policies should incentivize pollinator-friendly practices and regulate harmful chemicals.

Public Awareness and Citizen Participation: Educating farmers, policymakers, and the general public about the importance of pollinators is essential. Citizen science initiatives can contribute valuable data on pollinator distribution and trends.

Emerging Technologies and Innovations

Recent advancements in technology offer new opportunities for pollinator conservation. Remote sensing and GIS tools enable large-scale monitoring of habitats and pollinator activity. Artificial intelligence and machine learning can

analyse pollination patterns and predict declines. Innovations such as robotic pollinators are being explored; however, they cannot replace the ecological functions of natural pollinators. Instead, technology should complement conservation efforts.

Future Directions

Despite significant progress, several gaps remain in our understanding of pollinator ecology. There is a need for long-term monitoring studies, especially in tropical regions. The interactions between multiple stressors and their cumulative effects require further investigation. Region-specific studies are crucial for developing targeted conservation strategies. In India, integrating traditional knowledge with modern science can enhance pollinator conservation efforts.

Conclusion

Insect pollinators are indispensable to ecological sustainability and agricultural productivity acting as a silent workforce that sustains life on Earth. Their decline poses a serious threat to biodiversity, food security, and ecosystem resilience. Addressing this challenge requires a holistic and integrated approach involving habitat conservation, sustainable agriculture, policy support, and public engagement. Immediate and coordinated efforts are essential to protect these vital organisms and ensure the sustainability of ecosystem services for future generations.

References

- Klein, Alexandra-Maria, Vaissière, Bernard, E., Cane, James, H., Steffan-Dewenter, Ingolf, Cunningham, Saul, A., Kremen, C. and Tschamtker, T. (2007). Importance of pollinators in changing landscapes for world crops. *Proceedings of the Royal Society B: Biological Sciences*, 274: 303-313.
- Food and Agriculture Organization (FAO) (2019). The State of the World's Biodiversity for Food and Agriculture. Food and Agriculture Organization of the United Nations, Rome.
- IPBES (Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services) (2016). The Assessment Report on Pollinators, Pollination and Food Production. Secretariat of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services, Bonn.
- Potts, Simon, G., Biesmeijer, Jacobus, C., Kremen, Claire, Neumann, Peter, Schweiger, Oliver, Kunin and William, E. (2010). Global pollinator declines: trends, impacts and drivers. *Trends in Ecology and Evolution*, 25: 345-353.

Ecological Implications of Population Dynamics in Structuring Insect Diversity

Alisha Ray

Introduction

The population dynamics is a description (and prediction) of the size and age composition of a group of individuals of one particular species, and how the number and age composition of individuals in a population change over time (Ake Olson and Jan Stenlid, 2022).

$$\text{Change in Population Density} = (\text{Births} + \text{Immigration}) - (\text{Deaths} + \text{Emigration})$$

Population is a group of individuals (all members of a single species) who live together in the same habitat and are likely to interbreed. A population in a habitat is governed by the carrying capacity of the environment. Birth (natality), death (mortality), emigration and immigration are the 4 primary ecological events that influence the size of a population. Population dynamics is one of the fundamental areas of ecology, forming both the basis for the study of more complex communities and of many applied questions. Understanding population dynamics is the key to understanding the relative importance of competition for resources and predation in structuring ecological communities, which is a central question in ecology. The calculation of the intrinsic growth rate of a species from a life table is often the central piece of conservation plans. Similarly, management of natural resources, such as fisheries, depends on a population dynamics

approach to determine the largest sustainable yield. Secondary ecological events are factors (abiotic and biotic) that exert their impact on population density by influencing one or more primary ecological events. These may affect the frequency, extent, magnitude or duration of a primary ecological event.

Secondary ecological events are again broadly classified into 2 categories.

Density-Independent factors: These includes environmental conditions often weather or climate related that affect all individuals equally, regardless of the overall population density in that area.

Density dependent factors: It includes events or conditions that change in severity as a population's size increases or decreases. These are in short biotic factors like food sources, predation, parasitism, disease, competitors and so on.

What is Diversity?

It is the total of genes, species and ecosystems in a region. Insect diversity refers to the total of genes, species and insect ecosystems in a region.

Density-Independent factors

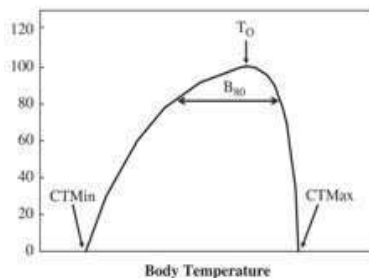
Temperature: Temperature is a fundamental climatic variable that plays a pivotal role in shaping ecosystems and influencing various aspects of biological activity. Insects are sensitive to temperature owing to their ectothermic nature (i.e. body

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temperatures closely approximate ambient temperatures) and extreme thermal conditions can therefore be detrimental to their fitness (Chown and Nicolson, 2004; Angilletta, 2009).

The insects remain active between the upper and lower tolerable limits of temperature but become inactive at both the extremes. Most of the insects survives in temperature between 0°C and 50°C with few exceptions that can survive even beyond the extremes of this range. The generalised thermal performance curve for insects showing the optimum temperature (T_o), performance breadth (B_{80}) and critical thermal maxima and minima (CT_{max} and CT_{min}) (Redrawn from Angilletta *et al.*, 2002).



In the context of insect activity, temperature exerts a profound influence on their behavior, physiology, and life cycles. Firstly, temperature determines the metabolic rate of insects, with higher temperatures generally leading to increased metabolic activity. This metabolic rate drives critical processes like foraging, reproduction, and growth. Temperature influences insect development rates, with warmer temperatures generally accelerating growth and maturation, while colder temperatures slow these processes. The temperature impacts insect behavior and activity patterns as it can serve as a cue for activities such as mating, migration, and emergence from diapause. Extreme temperature events, whether excessively hot or cold, can have

detrimental effects on insect populations, leading to mortality and population declines.

Effect of temperature in production of quality sterile male insects

Sterile insect technique depends greatly on the production of good quality sterile male insects that are released in high numbers into target wild populations (Calkins and Parker, 2005; Judd and Gardiner, 2005).

Adult thermal tolerance of *C. pomonella* at daily scales is critical to SIT success (through e.g. minimum temperatures required for flight to high temperatures possibly limiting flight and mating), thermal tolerance can be a crucial aspect of laboratory-reared moth quality (see discussions in Bloem *et al.*, 2006; Stotter and Terblanche, 2009; Chidawanyika and Terblanche, *in press*) and may also determine survival upon release in the wild. Typically, CM rearing and maintenance in SIR programmes use only constant, optimal temperatures, probably in order to maximise rearing productivity (Bloem *et al.*, 2004) regardless of the environmental conditions moths will be released into. This factor in particular may negatively impact the competitiveness of CM for SIR in the field. By contrast, a less well established method for improving CM for SIR is thermal preconditioning. Three groups of *C. pomonella* ($n=2000$ per group) larvae were exposed to three different ambient temperatures 20 ± 1 , 25 ± 1 , and 30 ± 1 °C for 6 days (developmental acclimation) before eclosion, upon eclosion transferred to 25 °C, and all three groups

had their critical thermal limits assayed thereafter. Both upper and lower critical thermal limits (CT_{max} and CT_{min}) to activity were affected by thermal acclimation occurring either in developing larvae or adult moths.

Low temperature acclimation ($20^{\circ}C$) reduced CT_{min} for both developmental and adult acclimation in CM. High temperature ($30^{\circ}C$) acclimation increased CT_{min} and CT_{max} in adult CM. For CT_{min} in either developmental or adult acclimation experiments, all three acclimation groups were statistically heterogeneous, with the rank order $20 < 25 < 30^{\circ}C$.

Field release trials showed a significant interaction effect between acclimation temperature and field temperature. Cold-acclimated moths were recaptured significantly more under cold conditions at sex pheromone traps, but not under warm conditions, and that warm-acclimated moths were recaptured in higher numbers under warm, but not cooler, conditions. These results show that rearing protocols can have dramatic effects on field performance under variable ambient temperatures in *C. pomonella* and that inducible plastic physiological responses are of direct relevance to CM control programmes.

Humidity: Water is an important for life. Environmental moisture factors are continuously variable. The different factors related to moisture includes precipitations, humidity, condensation and available surface water. Environmental moisture determines the survival and length of life of insects.

It is adversely affected by excess moisture. The different insect's metabolic activities are dependent upon water. A suitable balance is always maintained between the water content of the internal environment of the body and the moisture present in the external environment of atmosphere which includes humidity and rainfall. In insect body the water content varies from insect to insect from less than 50 percent to more than 90 percent of total body weight. Caterpillars comparatively have larger amount of water whereas the insects with hard bodies have lesser amount of water. More water is present in the active stages in insects in comparison to inactive stages.

For example,

Locusta migratoria live longer at lower humidity. The larvae of spruce budworm stop feeding in water saturated air. The infestation of *Chilo partellus* in experiment conducted by Zulfiqar *et al.* (2010) increased with decrease in temperature and relative humidity. The minimum infestation 16% was found at the temperature of $36.5^{\circ}C$ and relative humidity 68%. Maximum infestation 45% was found at temperature of $32.5^{\circ}C$ and relative humidity 50%. The following research was conducted in OUAT during 2016-17. From this, a portion is taken to understand the influence of humidity on insects.

Light: Light is very important factor for insects and its diversity. Its different parameters like photo-period, illuminance, wave length, intensity etc. affects various activities of insects more or less. Rarely, the light acts as a lethal factor.

Species Name	Category	Criteria	Countries of Occurrence	Type of Firefly	Females	Habitat Description
<i>Bicellonycha wickershamorum</i> (Southwest spring firefly)	VU	B1ab(iii)	USA, Mexico	Flashing	Winged	Montane seeps and marshes along permanent streams
<i>Bicellonycha wickershamorum piceum</i> (Gila Southwest spring firefly)	EN	B2ab(iii)	USA	Flashing	Winged	Montane seeps along permanent streams
<i>Bicellonycha wickershamorum wickershamorum</i> (Southwest spring firefly)	VU	B1ab(iii)	USA, Mexico	Flashing	Winged	Montane seeps and marshes along permanent streams
<i>Lampyrus germariensis</i> (Dalmatian glow-worm)	VU *	B2ab(iii)	Croatia, Montenegro, Bosnia and Herzegovina	Glow-worm	Flightless	Temperate broadleaf and mixed forests
<i>Lampyrus lareynii</i> (Corsican glow-worm)	VU *	B1ab(iii)	France	Glow-worm	Flightless	Humid microhabitats within Mediterranean woodlands and shrublands
<i>Lampyrus pallida</i> (Maltese glow-worm)	EN *	B1ab(iii)+2ab(iii)	Malta	Glow-worm	Flightless	Humid microhabitats within Mediterranean shrublands
<i>Lucidota luteicollis</i> (Florida scrub dark firefly)	VU	B1ab(iii)	USA	Diurnal	Flightless	Upland ridges within scrub, sandhill, and pine savannah
<i>Luciola novaki</i> (Black legged firefly)	EN *	B1ab(iii)+2ab(iii)	Albania, Montenegro	Flashing	Winged	Freshwater and estuarine marshes
<i>Luciola tuberculata</i> (Lumpy-necked flasher)	CR	B1ab(iii)+2ab(iii)	Hong Kong	Flashing	Winged	Shrublands and lowland forests along rivers
<i>Micronaspis floridana</i> (Florida intertidal firefly)	EN	B2ab(i,ii,iii)	USA, The Bahamas	Flashing	Winged	Salt marshes, mudflats, and mangroves in coastal areas
<i>Nyctophila calabriai</i> (Calabrian Nyctophila glow-worm)	EN *	B1ab(iii)	Italy	Glow-worm	Flightless	Riparian areas within woodlands
<i>Oculogryphus chenghoiyanae</i> (Chenghoiyan Otoretine firefly)	CR	B1ab(i,ii,iii,v)+2ab(i,ii,i,v)	Hong Kong	Glow-worm	Flightless	Shrublands and dense, natural woodlands

The reactions of insects to photoperiod light and other parameters vary between the species and between different life stages of the same species. Light has a great influence on the different factors of insects like the swarming, egg laying, changes in flight, prolongation of life, the emergence of many species, stimulating effect on insects etc. For example, the light stimulates egg laying in Praying Mantis and some other insects whereas it inhibits

oviposition in case of *Periplaneta*.

Light pollution as a major threat to fireflies

From past few years, according to the reports there is a decline in the populations of fireflies. 150 species of firefly species are enlisted in IUCN red list majority of which are living in America and Canada. As of now, fireflies are not facing any global extinction, but are at risk in many regions. Both the larvae and adult produce light. This light is produced

from the 7th abdominal segment. The light is emitted as a result of an internal chemical reaction and it is this light which helps them in courtship. This light is unique to each species. The differences is in the wavelength and the number of flashes. In the presence of artificial light, fireflies are forced to expend more energy in trying to flash brighter and have their signals noticed by prospective mates, although the effects vary among species which are receptive to different wavelengths. Current list of fireflies categorized as globally threatened with extinction according to the IUCN Red List criteria, geographic distribution, life history traits and habitat associations.

Density dependent factors

Competition: Same species or different species individuals lives in the same habitat, with similar requirements for food, protection and reproduction. There is a very tough competition for limited resources amongst them. The competition for food is very tough. Such a competition is disadvantageous to whole population. The fast feeders develop faster and may survive at the expense of slower individuals. The rule in the nature is survival of the fittest and weaker members are eliminated. This leads to the displacement of weaker species. Most displacements that we have identified were triggered by the introduction or invasion of an exotic species (78%), although other environmental factors may predispose a species to being displaced. Polyphagy and the lack of natural enemies often characterize invasive species that have large impacts on communities.

Such invasive species typically have their greatest impact on simple and anthropogenically disturbed habitats.

Mechanisms of competition leading to displacement

Differential resource acquisition: In this form of exploitation competition, all individuals have potential access to resources. However, when individuals of one species gather sufficient resources while individuals of another species cannot obtain sufficient resources, the latter species will be displaced. This differential resource acquisition is not driven by agonistic interactions, but by the intrinsic abilities of the species to obtain resources.

Differential female fecundity: When one species has greater realized fecundity than a competitor that competitor will be displaced. This mechanism applies not just to numbers of offspring, but also to the ability to produce proportionately more females from the same resources.

Differential searching ability: Differential searching ability is a form of exploitation competition where superior searchers locate and exploit resources faster than competitors. Thus over time, the superior searchers reduce the resource pool available to competitors. Differential searching behavior can occur between species in their location of ephemeral or discrete resources.

Resource preemption: Resource preemption occurs when a species utilizes critical resources before they become available to a competitor. This type of competition is not limited to species of a particular

feeding guild, or to a particular resource. For example, by attacking younger life stages of a common host than stages attacked by competitors, one parasitoid species diminishes the potential number of hosts available to its competitors and can displace those competitors. Likewise, a phytophagous species that consumes host plants before the foliage is suitable for another species, or before fruit has set can displace that species.

Resource degradation: Another factor leading to competitive displacement is the degradation of a resource by one species below the requirements for another. Unlike differential resource acquisition or resource preemption, a resource (e.g., food or breeding site) is still present but has been qualitatively degraded or altered by the actions of one species so that the development of individuals of another species is inhibited.

Predation

Prey-Predator interaction: Theoretically, Prey-predator interactions influence the structure and dynamics of an agro-ecosystem. No insect population exists as an isolated entity. Rather, at any location many populations of organisms interact to varying degrees in a community. Different species within an ecological community interact in a number of ways. In agroecosystems, the study of trophic interactions is important with regard to pest management. Individuals of a population feed on and in turn are fed upon other species (Tscharntke and Hawkins, 2004). Coccinellids and carabids are most widespread and abundant predators in many agricul-

tural systems. They are known to have a strong impact on aphid species (Hodek and Honek, 1996).

Various models have been developed to describe prey-predator interactions these include the classical Lotka-Volterra model, Rosenzweig-MacArthur model, Boxcar model.

Diseases: All insects share their biotic environment with parasites and pathogens. Diseases are highly density dependent and keeps the population of the insects at check. The diseases are caused by fungus, virus, bacteria, protozoa. Diseases are spread easily and faster when individuals are crowded. The chances of getting contact with the virulent microbe is higher at high density population. More specifically, because parasite transmission tends to be positively density-dependent, the per capita risk of infection generally increases with population density and individuals in crowds are generally under greatest threat from parasites (Anderson and May 1981).

Food sources: Quantity and quality of food determines the abundance of insect species. Here, food source is not only limited to plants but it also includes other sources like decaying fruits and vegetables, other insects etc. More the food more is the insect pests. Insects can be monophagous and polyphagous. In addition to this, quality is also very important factors. Non-availability of essential minerals and nutrients from the host can reduce their reproductive availability. Ex. DIMBOA in maize acts as resistance against insects like Asian corn borer and corn leaf aphids.

References

- Wertheim, B., van Baalen, E. J. A., Dicke, M., Vet, L. E. M. (2005). Pheromonemediated aggregation in nonsocial arthropods: an evolutionary ecological perspective. *Annual Review of Entomology*, 50: 321-346.
- <https://genent.cals.ncsu.edu/bug-bytes/dynamics/>
- Begon, M., Townsend, C. R. and Harper, J. L. (2006). *Ecology: From Individuals to Ecosystems*. 4th ed. Blackwell Publishing.
- Odum, E. P. and Barrett, G. W. (2005). *Fundamentals of Ecology*. 5th ed. Thomson Brooks/Cole.
- Price, P. W., Denno, R. F., Eubanks, M. D., Finke, D. L. and Kaplan, I. (2011). *Insect Ecology: Behavior, Populations and Communities*. Cambridge University Press.
- Southwood, T. R. E. and Henderson, P. A. (2000). *Ecological Methods*. 3rd ed. Blackwell Science.
- Talat, P. I., Shahnaz, A. R., Naureen, R., Tahira, R. and Muhammad Nadeem, A. K. (2011). Predator-prey relationship among species in the croplands of central Punjab, Pakistan. *Journal of Agriculture science*, 48(2): 153-157.
- Stuart, R. R. and John, T. T. (2002). Competitive displacement among insects and arachnids. *Annual Review of Entomology*, 47: 435-65.
- Muhammad, A. Z., Althaf, S. M., Asif, M. R., Amir, H. and Asim, H. (2010). *Pakistan Journal of Life and Social Sciences*, 8(1): 16-18.
- Frank Chidawanyika. (2010). M.Sc. thesis.
- Khaliq, A., Javed, M., Sohail, M. and Muhammad, S. (2014). Environmental effects on insects and their population dynamics. *Journal of Entomology and Zoology Studies*, 2(2): 1-7.
- Moereek, M. and Van Den Bosch. (1996). Insect-Pathogen dynamics: Stage-specific Susceptibility and insect density dependence. *Mathematical Biosciences*, 141: 115-148
- Sarkar, D. (2017). Effect of weather on population build up of major insect and natural enemies of aromatic rice under staggered planting. *M.Sc. thesis*.

The Silent Battlefield: How War Ravages Our Environment

Ravi Verma

Abstract

The environmental consequences of warfare are substantial and long-lasting, although their ecological effects often remain unrecognized. Contemporary conflicts result in land degradation due to bombings, landmines, and soil contamination, while also polluting water bodies through industrial and chemical runoff and exacerbating air pollution and greenhouse gas emissions. Habitat degradation precipitates a reduction in biodiversity, thereby triggering species extinctions and ecosystem collapses. The enduring environmental consequences of warfare, as evidenced by case studies from the Gulf War, Vietnam War, Syrian Civil War, and the ongoing conflicts in Ukraine, present considerable threats to human health, food security, and climate stability. Consequently, to mitigate these impacts effectively, comprehensive post-conflict environmental assessments, the implementation of sustainable demining and restoration practices, the reinforcement of international regulations, and active community engagement are imperative. Furthermore, recognizing the environment as both a victim and a facilitator of human resilience is critical for addressing the subtle devastation of war and promoting lasting ecological and societal recovery.

Introduction

Conflict has consistently played a pivotal role in the narrative of human history, influencing the development of nations, economies, and societies. The direct impacts on humanity fatalities, displacement, and economic downturn are clearly evident and often take centre stage in media reports. Conversely, a simultaneous and often overlooked crisis persists: the substantial and protracted environmental damage stemming from warfare. Modern conflicts, distinguished by advanced weaponry, widespread infrastructural destruction, and the deployment of chemical substances, generate a persistent environmental footprint that can persist long after the fighting has ceased.

The environmental ramifications of armed conflict are multifaceted and intricate. Forest ecosystems are subject to devastation via incineration or land clearing, while soils become contaminated with explosives, heavy metals, and chemical byproducts; concurrently, water sources are compromised by pollution stemming from industrial discharges and military activities. The application of defoliants, exemplified by Agent Orange during the Vietnam War, serves as a poignant illustration of the enduring ecological damage resulting from chemical warfare. Furthermore, the environmental problems already present are made worse by war. For example, the burning of fossil fuels, oil spills, and deforestation release carbon

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dioxide and other greenhouse gases, which then worsen climate change. The complex web of life, which is essential for maintaining ecological balance, faces significant threats. Ecosystems are often thrown out of balance by overhunting, habitat destruction, and chemical pollution, which can lead to the decline or extinction of many species. This ecological disruption has far-reaching consequences for human populations: diminished access to clean water, deteriorating agricultural lands, and weakened food security heighten human vulnerability in areas affected by conflict. The relationship between environmental degradation and human well-being highlights the critical importance of viewing ecosystems as both casualties and valuable assets in conflict and post-conflict planning. Moreover, conflicts hinder effective environmental governance. Entities prioritizing survival and military tactics often disregard environmental regulations, conservation initiatives, and climate policies, potentially inflicting considerable long-term harm on ecosystems and hindering post conflict recovery. Environmental degradation intensifies social and economic challenges, thereby generating a complex crisis that sustains a cycle of vulnerability and resource scarcity. By examining the root causes, resulting consequences, and possible solutions, this analysis highlights the importance of integrating ecological considerations into conflict management and post-conflict recovery. Addressing the environmental consequences of conflict is crucial, not just for ecological reasons but also for sustainable human

progress, regional stability, and global resilience.

The Ecological Cost of Modern Warfare

The Environmental Impact of Contemporary Armed Conflict. Contemporary conflict extends beyond traditional military engagements on designated battlefields. The deployment of heavy artillery, aerial bombardments, and chemical weapons yields significant repercussions for ecosystems. The United Nations Environment Programme (UNEP) indicates that conflicts can hasten the processes of deforestation, soil degradation, and species extinction. The environmental consequences of conflict can be divided into several key domains: land, water, air, biodiversity, and climate.

Soil Degradation and Contamination Issues

Armed conflicts frequently entail the deployment of explosives, landmines, and heavy vehicles, which result in significant physical alterations to landscapes. Bombardments devastate landscapes, and the presence of landmines and unexploded ordnance makes extensive areas hazardous for many years. Soil contamination arises from the presence of residues from explosives, fuel, and heavy metals, rendering agricultural practices nearly unfeasible. The Gulf War of 1991 left a lasting mark on Iraqi soil, thanks to oil spills and the deliberate setting ablaze of oil wells. Subsequent studies revealed that the soil's hydrocarbon and heavy metal content created "dead zones," areas where plants struggled to survive. Moreover, the enduring wars in Afghanistan have rendered extensive areas of land thousands of hectares dangerous due to unexploded ordnance.

This not only reduces the amount of land available for farming but also presents a serious risk to food security. Water sources are often contaminated and scarce during conflict.

Water Pollution and Scarcity

Water bodies are more vulnerable during times of conflict. Military campaigns often leave a trail of damage to vital infrastructure. Water treatment plants and dams are often damaged. This destruction then triggers the release of untreated sewage and industrial pollutants into nearby rivers and lakes. Oil spills resulting from naval operations or acts of sabotage, such as those observed in the Persian Gulf during the Gulf Wars, have inflicted enduring harm on marine ecosystems. The existence of chemical weapons adds another layer of risk. The Syrian conflict's devastation has spread far beyond the battlefield. The rivers, once vital to the region, now bear the weight of industrial pollution. The pollution stems directly from the destruction of factories by airstrikes. The pollution has hit both the local population and the wildlife hard. Further complicating matters, the continued draining of groundwater in areas affected by conflict is making desertification worse. As a result, this is denying both communities and ecosystems access to a reliable water supply, a resource that is absolutely vital.

Air Pollution and Atmospheric Impact

Air pollution, a byproduct of burning fossil fuels in everything from tanks to airplanes and munitions, unleashes a significant volume of greenhouse gases and tiny particles into the atmosphere.

The smoke from oil well fires, a defining characteristic of the Gulf War, can linger for long periods, severely impacting air quality and leading to respiratory problems for people living nearby. The environmental ramifications are substantial, particularly in relation to climate change, because carbon emissions stemming from armed conflicts exacerbate global warming. Moreover, the deployment of chemical and biological weapons leads to the pollution of both land and water, concurrently worsening air quality; this can precipitate long-term health issues for affected populations and further destabilize ecosystems. Therefore, the environmental damage caused by conflict is complex, affecting both the atmosphere and the soil.

Biodiversity Loss

Conflict zones pose a significant threat to biodiversity. Wildlife faces many difficulties. Habitat loss, the search for food, and the threat of harmful chemicals all have negative effects. Agent Orange, a powerful herbicide, saw widespread use during the Vietnam War. Its deployment devastated vast swathes of tropical forest, resulting in the disappearance of numerous plant and animal species. Likewise, the ongoing strife in the Democratic Republic of Congo has severely impacted rainforests, endangering species such as gorillas and elephants. The long-lasting effect often leads to the breakdown of local ecosystems. The extinction of key species triggers an ecological imbalance, which in turn accelerates environmental decline. A decrease in biodiversity significantly jeopardizes the welfare

of those reliant on natural resources, thus perpetuating a detrimental cycle of susceptibility affecting both human communities and ecological frameworks.

Climate and Global Environmental Impact

The environmental consequences of conflict go beyond local areas, potentially leading to global effects. Deforestation contributes to the release of sequestered carbon into the atmosphere, thereby amplifying the impacts of climate change. Extensive military operations play a substantial role in the increase of greenhouse gas emissions. NATO's activities in the Middle East and North Africa are believed to release millions of tons of CO₂ each year. Furthermore, conflicts hinder the effectiveness of environmental governance. Countries involved in conflict often overlook climate initiatives, measures against deforestation, and efforts to protect wildlife. This worsens global ecological problems, which can then lead to increased CO₂ emissions and further environmental damage in the affected areas.

Case Studies: War and Environmental Degradation

- ✓ The Gulf War (1990-1991) serves as a pertinent example; the intentional burning of Kuwaiti oil wells resulted in the environmental release of approximately 1.5 billion barrels of crude oil, which, in turn, inflicted considerable damage upon both marine and desert ecosystems. Moreover, the resulting smoke clouds caused air pollution that crossed borders, affecting areas as far away as India.

- ✓ The Vietnam War (1955-1975) also provides an example of this. The widespread use of herbicides led to the destruction of 20% of Vietnam's forests, a significant decrease in wildlife populations, and the lasting pollution of the soil.
- ✓ The ongoing Syrian Civil War, which began in 2011, provides a current example. Bombing campaigns and industrial destruction have engendered chemical pollution in rivers, soil contamination, and the collapse of water infrastructure, thereby precipitating a protracted public health and environmental crisis.
- ✓ Ukraine Conflict (2022-Present): Large-scale artillery shelling has damaged industrial sites and agricultural lands, causing both soil and water pollution. Satellite imagery has revealed forest destruction and urban environmental degradation on an unprecedented scale.
- ✓ Israel and Iran war (2026- Present): Heavy Artillery shelling damaged the various sites. The environmental damage caused by war isn't just a side effect; it's a hidden crisis that can last long after the fighting stops The Socio-Ecological Dimension

The socio-ecological perspective highlights the connection between armed conflict and environmental damage, which directly impacts human health. Contaminated water sources can lead to disease outbreaks, while soil degradation threatens food security. Moreover, the worsening of chronic respiratory problems is significantly worsened by air

pollution. Furthermore, the arrival of displaced populations from areas of conflict exacerbates ecological pressures within the regions they inhabit, thereby intensifying environmental strain. The welfare of human populations and the health of the environment are inextricably connected. Consequently, safeguarding ecosystems within conflict-affected zones is of paramount importance, not only from an ethical standpoint but also as a pragmatic approach to fortifying communities and mitigating the potential for future resource-related conflicts.

Pathways to Mitigation and Recovery

Despite the significant environmental consequences of conflict, restoration is attainable through cooperative endeavours. Rapid evaluations of soil, water, and air quality are essential for pinpointing potential risks and determining the most effective remediation approaches. Sustainable demining and disposal methods are evolving. Methods like biological demining, which use trained animals and robotic systems, offer the potential to lessen environmental damage. Reforestation and wetland restoration projects are crucial for revitalizing ecosystems and combating desertification. International Regulations and Environmental Protocols: Enhancing adherence to treaties such as the Geneva Conventions, which focus on safeguarding natural resources in times of conflict, has the potential to mitigate environmental damage. Community engagement, by involving local populations in ecological restoration, helps to manage natural resources sustainably and strengthens resilience.

Conclusion

The environmental repercussions of armed conflict are often overlooked in assessments of warfare. Despite this, the degradation of terrestrial, aquatic, and atmospheric resources, along with the loss of biodiversity, constitutes a substantial and enduring threat to both human survival and the overall well-being of the Earth. The decline of ecosystems is not a transient problem; rather, it signifies a persistent crisis that demands immediate international attention. In the context of ongoing global conflicts, it is crucial to acknowledge the environment's dual role as both a casualty and a significant contributor to resilience. The incorporation of sustainable post-conflict recovery strategies, coupled with international environmental protections, presents an opportunity to mitigate the frequently disregarded repercussions of warfare, thereby paving the way for a more robust and secure future.

References

- Edo, G. I., Jikah, A. N., Akpogheli, P. O., Owheruo, J. O., Isoje, E. F., Igbuku, U. A. and Essaghah, A. E. A. (2025). Pollution and Biodiversity Loss: A Comprehensive Review of Impacts and Mechanisms. *Al-Mustaqbal Journal of Sustainability in Engineering Sciences*, 3(1).
- Verma, R. (2025). *International Journal of Sciences and Innovation Engineering Microplastics: Environmental Ubiquity, Biological Fate, and Human Health Implications*, 2(8).

- Aborode, A. T., Otokpa, O. J., Abdullateef, A. O., Oluwaseun, O. S., Adegoye, G. A., Aondongu, N. J., Oyetunji, I. O., Akingbola, A., Scott, G. Y., Kolawole, B. O. and Komakech, J. J. (2025). Impact of climate Change-Induced flooding water-related diseases and malnutrition in Borno State, Nigeria: a public health crisis. *Environmental Health Insights*, 19: 11786302251321683.
- Lawrence, M. J., Stemberger, H. L., Zolderdo, A. J., Struthers, D. P. and Cooke, S. J. (2015). The effects of modern war and military activities on biodiversity and the environment. *Environmental Reviews*, 23(4): 443-460.
- Saha, A. and Thakur, M. (2025). Effects of environmental change on wildlife health. In *Biotechnology Innovations for a Sustainable Future* (pp. 1845-1861). https://doi.org/10.1007/978-981-97-9859-9_89
- See, S., Opdyke, A. and Banki, S. (2025). A review of the climate change-disaster-conflict nexus and humanitarian framing of complex displacement contexts. *Climate and Development*, 1-14.
- Segala, F. V., Guido, G., Stroffolini, G., Masini, L., Cattaneo, P., Moro, L., Motta, L., Gobbi, F., Nicastri, E., Vita, S., Iatta, R., Otranto, D., Locantore, P., Occa, E., Putoto, G., Saracino, A. And Di Gennaro, F. (2025). Insights into the ecological and climate crisis: Emerging infections threatening human health. *Acta Tropica*, 262: 107531.
- Filho, W. L., Fedoruk, M., Eustachio, J. H. P. P., Splodytel, A., Smaliychuk, A. and Szyńska-Jóźwik, M. I. (2024). The environment as the first victim: The impacts of the war on the preservation areas in Ukraine. *Journal of Environmental Management*, 364: 121399.
- Verma, R. (2025). The Gomti River at Risk: An Integrated Review of Pollution Sources, Environmental and Public Health Impacts, and Sustainable Management Pathway. In *Journal of Indian Association for Environmental Management*, 45(3).
- Verma, R. (2025). Comprehensive Analysis of Marine Pollution: Sources, Environmental and Socioeconomic Impacts, and Sustainable Mitigation Strategies with Public Awareness. *IARJSET*, 12(10).
- Nixon, R. (2011). *Slow violence and the environmentalism of the poor*. Harvard University Press.

Threatened Treasures: India's Endangered Medicinal Plants

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Introduction

Since the beginning of time, people have been interested in medicinal plants. The use of therapeutic plants has a long history in almost every civilization. For primary healthcare, around 80% of people in underdeveloped nations rely on traditional medicine, which uses plant extracts in roughly 85% of cases. India is one of the 12 mega diversity hotspot nations with a great diversity of biotic resources, and it occupies 2.4% of the world's land area with 8% of the world's biological diversity. The Eastern Himalayas and the Western Ghats are India's two main hotspots out of 34 that have been identified. The bio-geographic position of India is so unique that all known types of ecosystems range from coldest place like the Nubra Valley with “57°C, dry cold deserts of Ladakh, temperate and Alpine and subtropical regions of the North-West and trans-Himalayas, rain forests with the world’s highest rainfall in Cherrapunji in Meghalaya, wet evergreen humid tropics of Western Ghats, arid and semiarid conditions of Peninsular India, dry desert conditions of Rajasthan and Gujarat to the tidal mangroves of the Sunderban which harbours about 47000 species of plants of which 17 000 are angiosperms (Bapat *et*

al., 2008). India is also rich in medicinal plant diversity with all the three levels of biodiversity such as species diversity, genetic diversity, and habitat diversity (Mukherjee and Wahile, 2006). Across the country, the forests are estimated to harbour 90% of India’s total medicinal plants diversity. Only about 10% of the known medicinal plants of India are restricted to non- forest habitats. Even though there are only 18,665 species of flowering plants overall, their intraspecific variability makes it among the highest in the world. Only roughly 3000 of the 18,665 plants are used in different formulations by traditional medical systems including Ayurveda, Siddha, and Unani (Schippmann *et al.*, 2006). Estimates of the number of species used medicinally include: 35,000-70,000 or 53,000 worldwide; 10,000-11,250 in China; 7500 in India; 2237 in Mexico; and 2572 traditionally used by North American Indians. However, there is no reliable figure for the total number of medicinal plants on Earth, and numbers and percentages for different countries and regions vary widely. The International Union for Conservation of Nature and Natural Resources (IUCN) Red List of Threatened Species includes 560 plant species from India, of which 247

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are classified as threatened. According to estimates from the IUCN, approximately 34,000 species, or 12.5% of all vascular plants worldwide, are threatened to varied degrees (Phartyal *et al.*, 2002). Extinct, severely endangered, endangered, vulnerable, near threatened, least concern, data insufficient, and not evaluated are among the categories recognized by IUCN. Rare species are those with limited populations that are at risk but are not currently endangered or vulnerable. A large number of them are in danger of going extinct. Over the past few decades, there has been a growing global preference for herbal medicine, which has been followed by a delayed rise in awareness of the world's diminishing stock of medicinal plants. The majority of the plants utilized in phytopharmaceutical formulations come from naturally occurring growing regions. Due to destructive harvesting methods and overharvesting for pharmaceutical production with little to no consideration for the future, the genetic diversity of medicinal plants worldwide is being threatened at an alarming rate. Their existence is also threatened by the widespread destruction of the plant-rich ecosystem brought on by urbanization, agricultural expansion, forest degradation and other factors.

Different Endangered Medicinal Plants

Aegle marmelos: *Aegle marmelos* (L.) Corr., (Family Rutaceae) commonly known as “Bael Tree” is a popular vulnerable medicinal plant mostly found in tropical and subtropical regions. Almost all parts of the tree are used in preparing herbal medicine for

treating diarrhea, dysentery, dyspepsia, malaria, fever, jaundice, and skin diseases such as ulcers, urticaria, and eczema. The plant is rich in alkaloids, among which aegline, marmesin, marmin, and marmelosin are the major ones.



Acorus calamus: Often referred to as “sweet flag” or “bach,” *Acorus calamus* Linn. (Family Araceae) is a significant endangered medicinal plant. This herb is semi-aquatic, with long, sword-shaped leaves and creeping rhizomes. In addition to being used to treat epilepsy, mental illnesses, chronic diarrhea, dysentery, bronchial catarrh, intermittent fevers, and tumors, the rhizomes have anti-spasmodic, carminative and anthelmintic qualities.

Curcuma caesia: *Curcuma caesia* Roxb. is one of the rarest medicinal plants used traditionally for the mitigation of various ailments. Strong aromas and therapeutic qualities are possessed by the bluish-black tuberous rhizomes. Numerous illnesses have been treated with this plant since ancient times (Borah *et al.*, 2019). For generations, rhizome has been utilized as a traditional medicine due to its many biological qualities. Numerous Indian tribes

also use the rhizomes as traditional medicine to treat leprosy, cancer, menstrual disorders, hemorrhoids, epilepsy, antihelminthic, and aphrodisiac conditions. Using leaf or rhizome extract to treat bronchitis, inflammation, hemorrhoids, leukoderma, piles, and asthma. Since ancient times, people have used plant secondary metabolites as antimicrobial agents. In recent years, there has been a renewed interest in the use of plant parts as antimicrobial agents, as some of the synthetic antibiotics can become ineffective due to resistance by the human body.

***Peganum harmala*:** *Peganum harmala* L. (Syrian Rue), a perennial herb of the Nitrariaceae family with therapeutic use, is found in semi-arid regions of central Asia, North-West India, and North Africa. In terms of medicine, this plant's fruits and seeds have narcotic, hypnotic, antipyretic, antispasmodic, emetic, diuretic, hallucinogenic, digestive, and uterine stimulating properties (Chatterjee, 1997). In Iran and Turkey, carpets are frequently colored with a crimson dye made from seeds. In cases of rheumatism, asthma, colic, dysmenorrhea, hiccups, hysteria, and neuralgia, leaves can be helpful. Additionally, the plant has been utilized as an insecticidal agent, antibiotic, antitumoral, and to treat malaria.

***Bacopa monnieri*:** *Bacopa monnieri* belonging to the family Scrophulariaceae is a very popular herb in India for longevity and mental function. It is used to decrease fatigue and depression, and to stimulate the sex drive. It energizes the central nervous system, and aids the circulatory system, soothes and minim-

izes varicose veins and helps to minimize scarring. It is also useful in repairing skin and connective tissues and smoothing out cellulite. It is generally considered an Ayurvedic “age tonic” restoring youth and vitality. Brahmi has been used by Ayurveda in India for almost 3000 years.

***Simmondsia chinensis* (Jojoba):** It is a member of the Simmondsiaceae family. It is a dioecious, evergreen desert shrub that grows freely in the Sonora desert of southern and Baja California, northern Mexico, and Arizona. Nowadays, jojoba is grown for commercial use in the United States, Argentina, Australia, Chile, Egypt, India, Israel, Mexico, Peru, and South Africa. The pharmaceutical, cosmetic, and industrial lubricant industries widely use jojoba seed oil due to their essential chemical constituents.

***Sapindus mukorossi*:** It is popularly known as ‘Ritha’ and ‘Soapnut’, is a most important deciduous tree of tropical and sub-tropical regions of Asia. The fruit of this tree contains saponins, the most active secondary metabolites extracted from this plant. It is a good substitute for washing soap and is as such used in preparation of quality shampoos, detergents etc. The fruit is of considerable importance for its medicinal value for treating a number of diseases like common cold, pimples, epilepsy, constipation, nausea etc.

***Glycyrrhiza glabra*:** Assyrian tablets from circa 2000 BC and Chinese herbals from the same era both mention its use, making it one of the most well-known medications in ancient history.

It has the property of quenching thirst if one holds it in the mouth, according to Theophrastos of Lesbos, who wrote in the fourth century BC. The plant was given its botanical name by Dioscorides (Greek: riza = root, glukos = sweet). Its name, a perversion of glycyrrhiza, was Lycorys in the 13th century. A member of the Fabaceae family, liquorice (*Glycyrrhiza glabra*) has long been used in medicine and cooking. Licorice has strong properties of its own, especially for ulcers and adrenal insufficiencies, and is used to flavor and sweeten candies and medicinal medicines.

***Stevia rebaudiana* Bertoni.:** It belonging to the family of Asteraceae is a perennial herb. This plant is a natural sweetener and famously known as “Sweet Weed”, “Sweet Leaf”, “Sweet Herbs” and “Honey Leaf”, which is estimated to be 300 times sweeter than cane sugar. It naturally grows in low lying areas on poor sandy acidic soils adjacent to swamps, and so is adapted to and requires constantly wet feet or shallow water tables. It grows up to 1 m tall and has leaves 2-3 cm long. The leaves are the source of diterpene glycosides, stevioside and rebaudioside. Stevioside is regarded as a valuable natural sweetening agent because of its relatively good taste and chemical stability (Yoshida, 1986).

***Pterocarpus santalinus* L.:** *Pterocarpus santalinus* L. popularly known as Red Sanders belonging to family Fabaceae is an endemic species confined to Southern parts of Eastern Ghats of India especially in Andhra Pradesh. The pinnately compound leaves typically shed between January and March.

Large yellow raceme blooms and a fresh flush of foliage are produced as summer approaches. Red Sanders heartwood is highly sought for in both the home and foreign markets, and its wavy grain is prized. The heartwood can accumulate various elements and rare earth elements like strontium cadmium, zinc, copper and uranium. The wood has different uses in traditional and folklore medicines and is used for the treatment of diabetes, prickly heat, skin diseases and for various other ailments.

***Tylophora indica* (Burm.F.) Merrill.:** It commonly known as “Antmool” or “Dama Bel” belonging to family Asclepiadaceae is an important endangered medicinal plant. It is a perennial branched climber having cylindrical, twinning stem with long fleshy roots. Leaves are ovate oblong to elliptic oblong and acute at tip. Flowers are bisexual, minute and grow in umbellate cymes. Corolla is greenish yellow outside and purplish within. It is found in the plains, forests, hilly slopes and outskirts of forests. It forms dense patches in moist and humid conditions and the plant shows stunted growth in the areas with lesser rainfall. Numerous illnesses and conditions are treated with it as a traditional medicine, most notably rheumatism, allergies, dermatitis, bronchial asthma, and bronchitis.

Conservation Strategies for Endangered Medicinal Plants

Rural residents mostly rely on the trees and vegetation in their surroundings for fuel, medicine, and wood. Alternative fuels and pricey contemporary medications are out of reach for this group.

As a result, there is ecological loss and environmental degradation, for which significant action must be taken. By discouraging people from cutting down trees and encouraging them to plant quickly growing native trees for household use, medicinal plants can be conserved. However, conservation cannot be significantly aided by this alone. Therefore, it is necessary to create and implement other, more recent conservation techniques. For the same, biotechno-logical methods and techniques must be applied. In-situ method of conservation deals with the “on-site conservation” of the wild genetic diversity in natural habitat. In India, the conservation of forest areas pre serves through Protected Areas like National Parks, Wildlife Sanctuaries and Biosphere Reserves. The Government should prepare a policy at national level on the conservation and utilization of medicinal plants in protected areas. This type of conservation is achieved both by setting away areas as nature reserves and wild nurseries and by ensuring that as many wild species as possible can still survive in managed habitats, like farms and plantation forests (Soule *et al.*, 2005). Ex-situ conservation deals with the “off-site conservation” of the wild genetic resources in natural habitat. It includes the collection, preservation and maintenance of certain genetic resources from wild. Ex-situ method of conservation is a complementary action to conserve the genetic diversity, thereby reducing pressure on wild environments and enhancing raw material availability.

Conclusion

The demand for therapeutic plants is growing increasingly every day, which is depleting naturally existent resources. In order to compensate for the loss of wild plant sources and meet the demand for medical plants, it is imperative that we concentrate on the conservation of medicinal plants. The conservation management and sustainable use of medicinal plants for human healthcare requirements can be started and supported by a variety of conservation strategies. The demand for medicinal plants has expanded due to the global acceptance of Ayurveda, the holistic science of medicine that has been practiced and used by Indians for generations, according to the World Health Organization. For primary healthcare, the majority of people in underdeveloped nations like India rely on traditional medical systems like Ayurveda. Growing demand for therapeutic plants causes illogical deforestation, which depletes natural resources. Furthermore, the variety of medicinal plants is further reduced as a result of man-made and natural disasters.

References

- Bapat, V. A., Yadav, S. R. and Dixit, G. B. (2008). Rescue of endangered plants through biotechnological applications. *National Academy of Scientific Letteres*, 31: 201-10.
- Mukherjee, P. K. and Wahile, A. (2006). Integrated approaches towards drug development from Ayurveda and other Indian system of medicines. *Journal of Ethnopharmacology*, 103(1): 25-35.

- Borah, A., Paw, M., Gogoi, R., Loring, R., Sarma, N., Munda, S., ... and Lal, M. (2019). Chemical composition, antioxidant, anti-inflammatory, anti-microbial and in-vitro cytotoxic efficacy of essential oil of *Curcuma caesia* Roxb. leaves: An endangered medicinal plant of North East India. *Industrial Crops and Products*, 129: 448-454
- Chatterjee, A. and Pakrashi, S. C. (1991). The treatise on Indian medicinal plants, Vol. 3. *New Delhi: Publication and Information Directorate, 1995.*
- Phartyal, S. S., Thapliyal, R. C., Koedam, N. and Godefroid, S. (2002). Ex situ conservation of rare and valuable forest tree species through seed-gene bank. *Current Science*, 1351-1357.
- Schippmann, U. W. E., Leaman, D. and Cunningham, A. B. (2006). A comparison of cultivation and wild collection of medicinal and aromatic plants under sustainability aspects. *Frontis*, 75-95.
- Soule, M. E., Estes, J. A., Miller, B. and Honnold, D. L. (2005). Strongly interacting species: conservation policy, management, and ethics. *Bioscience*, 55: 168-76.
- Yoshida, S. (1986). Studies on the Production of Sweet Substances in *Stevia rebaudiana*: 1. Simple determination of sweet glucosides in Stevia plant by thinlayer chromato-scanner and their accumulation patterns with plant growth. *Japanese Journal of Crop Science*, 55(2): 189-195.

New Generation Phytohormones

Harish Menpadi, Amaregouda A. and I. Balakrishna Reddy

Introduction

In the higher plants, the regulation, coordination of metabolism, growth, and morphogenesis efficiently depend on chemical signals produced by the plant itself. In the 19th century many of our current concepts about intercellular communication in plants were derived from research conducted in animals and hence the analogy of some terms and concepts. In animals the chemical messengers mediating intercellular communication are called hormones (Greek word 'Hormaein' means to stimulate), whereas in plants, growth and other physiological functions are mediated by chemical messengers called plant hormones or phytohormones. The term phytohormone is strictly used to name the compound chemicals synthesized inside the plant, which can be transferred and used in specific physiological communication processes, not including substances of xenobiotic origin. However, the terms plant growth regulators and phytohormone are sometimes often used analogously. Plant growth regulators (PGRs) have a significant impact on the growth, development, and yield of a variety of crops and decorative plants. PGRs are useful tools for horticultural and agricultural activities since they are

chemical molecules that can either stimulate or hinder plant growth processes. An overview of conventional plant growth regulators and their importance in affecting plant growth and development is given in this article. PGRs have been thoroughly studied and used to control plant growth and improve the quality of ornamental potted and bedding plants (Bergstrand, 2017). Besides natural phytohormones, it is possible today to find synthetic and biotechnological commercial products, referred as plant growth regulators, which are well known for their regulatory effects (Andresen and Cedergreen, 2010). Thus, plant growth stimulators are synthetic, biological, biosynthetic substances, or systems, able to produce an effect on plants; some examples are naphthalene acetic acid, or ANA, which is a root growth promoter and bacterial inoculate able to contribute with the nitrogen fixing and the strengthening of the rhizosphere. The global market for plant growth regulators, including auxins and cytokines, was estimated to be worth \$5.72 billion in 2019 and is projected to grow at a compound annual growth rate of 8.5% between 2020 and 2027, primarily in fruit and vegetable crops, oilseeds, cereals, and legumes, among other sectors.

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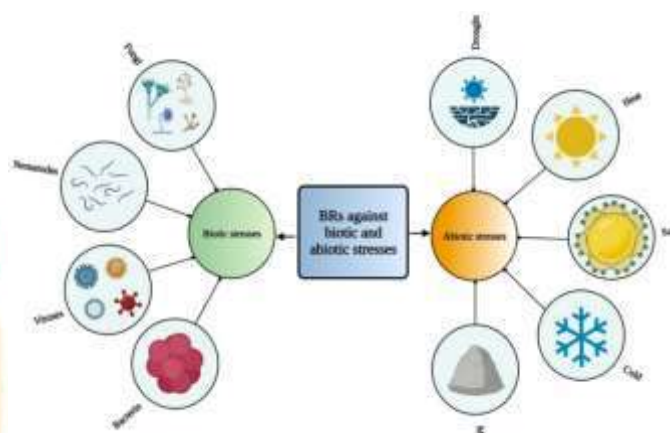
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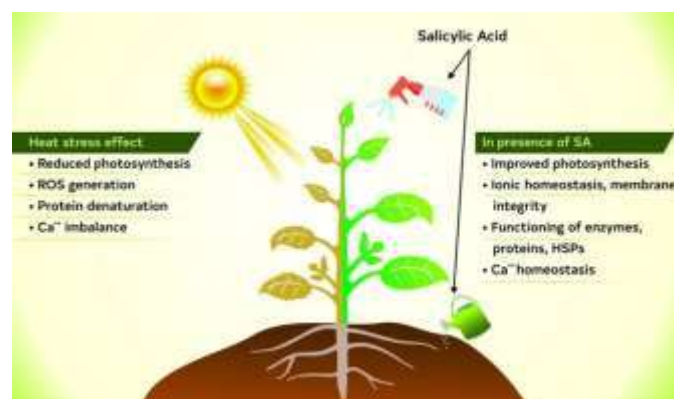
The use of these chemical compounds in the development of the agricultural industry is crucial to food security, the steady supply of agricultural products, and the subsequent creation of jobs. Additionally, medicinal chemistry has been increasingly interested in the biological activity of tiny molecules on plants, including some plant hormones, in an effort to find new fields for scientific and commercial advancement in recent years.

Brassinosteroids: Brassinosteroids (BR) are a new type of phytohormones with significant growth promoting influence. First identified from *Brassica napus* pollen, brassinosteroids (BRs) are plant-specific steroidal hormones distinguished by their polyhydroxylated sterol structure. BR is thought to be distributed in several plant species and serve a variety of roles in regulating a wide range of plant growth and developmental processes. In addition to responding to diverse biotic and abiotic challenges, they control a wide range of physiological processes, including seed germination, cell elongation, cell division, senescence, vascular differentiation, male fertility, blooming, reproduction, root growth, and photomorphogenesis. Numerous studies have been performed to support BR as vital plant growth regulators for contemporary agriculture because of their versatile mode of actions. The first application of BRSTs (Brassinosteroids) is in agriculture, where they help plants cope with abiotic and biotic stresses such as salt and drought, temperature extremes, and pathogen attacks. BRSTs can also regulate flowering time in some plant species through external applic-

ation. Plants lacking BRSTs often show dwarfism, short petioles, delayed flowering, and reduced fertility (Peres *et al.*, 2019). BRSTs have proven effective in increasing seed and leaf yields in various legume, cereal, and vegetable crops. For agricultural use, BRSTs can be applied by spraying, spreading, coating, or dipping plants, their parts, or soil. The application amount depends on BRST structure, formulation, plant species, and the desired outcome.



Salicylic acid: Salicylic acid (SLAc) plays an essential role in the activation and regulation of multiple responses to biotic and abiotic stress. This phytohormone was first isolated in 1928 from willow bark in Munich by Jhon Buchner. SLAc is a plant phenolic compound structurally formed by an aromatic ring with a hydroxyl group or its functional derivatives.



SLAc is an analogue of acetylsalicylic acid (AcSLAc) better known as aspirin, in some plant species it has been found in concentrations ranged among 1 mg g^{-1} and 37.19 mg g^{-1} depending on the species and tissue tested (Hayat and Ahmad, 2007). Numerous physiological and biochemical functions, including photosynthesis, ion uptake, membrane permeability, enzyme activity, flowering, heat production and growth and development of plants. As a result, agriculture is a natural application field for SLAc and AcSLAc. Other phenolic compounds, such as gentisic acid and other SLAc equivalents, are exogenous substances that can speed up the development of dry mass and leaf area. The species assessed, the method of application, and the quantity of SLAc utilized all affect how plants react to its use. However, SLAc has been found to be a component of defense mechanisms during interactions between plants and microorganisms, such as bacteria, yeasts, and viruses. At first, SLAc is collected in the nearby infected tissue before spreading throughout the plant to cause acquired systemic resistance in the plant's distant, uninfected sections (Maruri-López *et al.*, 2019). Foods, candies, drinks, and medications can all be flavored with SLAc analogs and derivatives. Furthermore, AcSLAc's applicability in medicine is widely recognized.

Strigolactones: Strigolactones (STGLs) are a class of plant hormones generated from carotenoids that are found in a variety of plant taxa, including higher plants and mosses. They are crucial for the stimulation and branching of parasitic plants and

arbuscular mycorrhizal fungal development and symbiosis in soil. In 1966, Strigol was the first STGL to be isolated from cotton root exudate. The plant genus *Striga*, which frequently parasitizes this crop, is connected to its name. The induction of secondary growth, acceleration of leaf senescence, stimulation of internode growth and root elongation, suppression of axillary bud growth, and production of adventitious and lateral roots are among the developmental processes regulated by STGLs. potential use of STGLs is their use in nutrient-poor soils and in organic farming to enhance nutrient uptake from root symbiosis with nutrient-fixing microorganisms under conditions of nutritional stress.

Karrikins: The smoke created by burning plant matter contains a class of chemically defined plant growth regulators called karrikins. Karrikins work well to awaken the seeds of a number of species that have adapted to live in areas that frequently experience smoke and fire. Recent research has shown that karrikins have an impact on seed germination and seedling growth in species that would not normally experience fire, indicating that their influence may extend far beyond fire ecology. This is illustrated by recent studies that show how precisely and sensitively *Arabidopsis thaliana* seedlings respond to karrikins in smoke.

Melatonin and Serotonin: Two important indoleamines that are produced from tryptophan are serotonin and melatonin. Stress signals appear to be linked to a precise control of auxin and serotonin production through tryptophan level modulation.

MEL's capacity to postpone senescence has also been extensively studied, and we now have a better understanding of the possible mechanisms of action. The capacity of MEL to support the development of new tissues while preserving aging tissues is an intriguing feature. It has been determined that MEL achieves this maintenance through metabolic and genetic mechanisms. From a metabolic standpoint, MEL's antioxidant ability can sustain the photosynthetic process, limiting the breakdown of chlorophyll and boosting photosystem II's efficiency. It can also control the metabolism of sugar and nitrogen and stop the breakdown of proteins.

Conclusion

One of the most important aspects of the function and regulation of phytohormones in plants is linked to the multiple interactions between them and the responses to the environmental conditions. Although this aspect is not discussed in this review, it is significant when making decisions on the use of different plant hormones, taking into account the plant species to be evaluated, the stage of development, the environmental conditions of the surroundings and the chemical messenger to be used. When phytohormones are applied to plants, remarkable changes can be seen either directly or indirectly. The majority of phytohormones' biosynthesis pathways have been discovered, and the genes controlling them have been cloned and characterized, which has greatly expanded the field of plant research. Previously, research on phytohormones was slower than that of mammalian hormones.

References

- Andresen, M. and Cedergreen, N. (2010). Plant growth is stimulated by tea-seed extract: a new natural growth regulator? *Hort Science*, 45(12): 1848-1853.
- Bergstrand, K. J. I. (2017). Methods for growth regulation of greenhouse produced ornamental pot-and bedding plants-a current review. *Folia Horticulturae*, 29(1): 63-74.
- Hayat, S., Ali, B. and Ahmad, A. (2007). Salicylic acid: biosynthesis, metabolism and physiological role in plants. In *Salicylic acid: A plant hormone* (pp. 1-14). Dordrecht: Springer Netherlands.
- Maruri-López, I., Aviles-Baltazar, N. Y., Buchala, A. and Serrano, M. (2019). Intra and extracellular journey of the phytohormone salicylic acid. *Frontiers in Plant Science*, 10: 423.
- Peres, A. L. G., Soares, J. S., Tavares, R. G., Righetto, G., Zullo, M. A., Mandava, N. B. and Menossi, M. (2019). Brassinosteroids, the sixth class of phytohormones: a molecular view from the discovery to hormonal interactions in plant development and stress adaptation. *International Journal of Molecular Sciences*, 20(2): 331.

Mimics and Masters: The Complex World of Spider-Ant Interactions

Hemangi P. Chaudhari, Pratibha Kurkute and Manisha Kondiram Balsane

Introduction

In terrestrial ecosystems, spiders and ants are ubiquitous and diverse generalist predators. Most Central European ant species are omnivores, being able to prey on a wide range of other invertebrates as well as to take up nutrients from plants indirectly by trophobiosis with phloem-feeding insects. Spiders and ants are potential competitors and mutual predators. Intrigued predation, i.e. the feeding on species of the same guild, is common in natural communities and enhances the reticulate nature of a food web. Further, intraguild predation has been characterized as an important feature structuring arthropod communities. Most spiders are solitary, all-purpose insect predators. Like most arthropod predators, most spiders dislike eating ants since they are typically hostile, some are poisonous, and most are just unpleasant for a number of reasons. However, hundreds of arthropod species coexist alongside ants in one way or another. In addition to more dramatic morphological changes like abdominal constrictions and/or cephalothorax constrictions, which give the impression that the spider has more than two body parts, morphological adaptations that confer mimetic resemblance to ants include color pattern similarities (Benjamin, 2004).

The intricate relationships between spiders and ants have captivated scientists for centuries, offering a glimpse into the complex and often mysterious world of arthropod interactions. Spiders and ants, two of the most diverse and ecologically successful groups of organisms on the planet, have evolved a range of fascinating interactions that span the spectrum from predation to mutualism. These interactions not only shape the structure and function of ecosystems but also provide valuable insights into the evolution of behavior, ecology, and morphology. Spiders, with their diverse array of species and adaptations, have evolved to occupy a wide range of ecological niches, from the driest deserts to the wettest rainforests (Hölldobler and Wilson, 1990). Ants, on the other hand, are renowned for their social complexity, communication, and cooperation, making them a dominant force in many ecosystems. The interactions between these two groups are multifaceted, with spiders preying on ants, ants preying on spiders, and even instances of mutualism where both species benefit from each other's presence (Cushing, 2012). One of the most intriguing aspects of spider-ant interactions is the phenomenon of myrmecophily, where spiders have evolved to mimic ants in order to deceive and prey on them. This remarkable example

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of convergent evolution highlights the intense selective pressure driving these interactions and the extraordinary adaptations that have evolved in response. Myrmecophily has been observed in several spider families, including the Salticidae (jumping spiders) and the Araneidae (orb-web spinners), demonstrating the widespread nature of this phenomenon (Jackson and Pollard, 2005). In addition to predation and mimicry, spiders and ants also engage in more cooperative interactions, such as mutualism, where both species benefit from each other's presence (Nelson & Jackson, 2006). For example, some spiders have been observed living within ant colonies, where they feed on ant prey and provide protection to the ants in return.

Types of Interaction between Spiders and Ants

The interactions between spiders and ants are diverse and complex, ranging from predation to mutualism. These interactions are shaped by the evolution of various adaptations and strategies employed by both spiders and ants to survive and thrive in their environments.

Predation: One of the most common interactions between spiders and ants is predation, where spiders feed on ants as a source of nutrition. Many spider species, such as the jumping spider *Portia*, are specialized ant-eaters, using their speed, agility, and cunning to catch ants. Some spiders, like the Myrmecophagous spiders, have evolved to mimic ants in appearance and behavior, allowing them to infiltrate ant colonies and prey on the ants. Some spiders, like the Myrmecophagous spiders, have

evolved to mimic ants in appearance and behavior, allowing them to infiltrate ant colonies and prey on the ants.

Mimicry: Mimicry is another common interaction between spiders and ants, where spiders mimic ants to avoid predators or attract prey. Many spider species, such as the *Myrmecoides* spiders, have evolved to resemble ants in appearance, movement, and behavior, allowing them to blend in with ant colonies and avoid detection. Some spiders, like the Ant-mimicking jumping spider, even mimic the chemical signals used by ants to communicate, allowing them to infiltrate ant colonies and prey on the ants. Mimicry can also be used by spiders to attract prey, such as the Aggressive mimic spider, which mimics the appearance and behavior of an ant to lure in other ants.

Ant-Spider Myrmecophily: *Myrmeco philes* are defined as ant guests, arthropods that have evolved close associations with ant species, often living alongside the ants or within the ant colonies. Arthropods symbiotic with ant hosts typically experience a stable microclimate, plentiful food (either in the form of other symbionts, the hosts themselves, or other resources brought into the colony by the hosts), and protection from their own predators and parasites. The degree of integration into the colonies varies greatly from species with just a loose affiliation or association with the ant nests to symbionts that spend their entire lives within the ant nests and fail to thrive when removed from this habitat (Nelson *et al.*, 2009). Depending on their natural history, these

symbionts may have a neutral, positive, or negative impact on the host colonies. The host should be able to identify and either attack or expel these visitors from the nest if the myrmecophile's effect on the host is severe enough. For instance, the myrmecophile *Masoncus pogonophilus* Cushing (Linyphiidae) consumes collembolans and other symbionts that are present in the harvester's colonies. *Pogonomyrmex badius*, an ant (Latreille) Because collembolans, the spiders' main food, graze fungal spores located inside the nest chambers, especially the seed storage chambers, this spider may therefore have a somewhat detrimental influence on the colonies of these ants. It has been observed that some ant colonies are more vulnerable to myrmecophile invasion than others. Colonies with several queens (polygynous colonies), colonies with various nest sites (polydomous colonies, which are sometimes also polygynous), and very large colonies are characteristics of host colonies that are most vulnerable to invasion by myrmecophiles.



Ant-Spider Myrmecophagy: Spiders, like other arthropod predators, generally avoid preying upon ants. However, ants have been documented as part of the diet for well over 100 species of spiders. Fossil evidence of spider myrmecophagy can be found in Baltic amber specimens dating back 30 to 50 million

years. One specimen shows a spider with an ant in its chelicerae, while another contains an inclusion of spider silk with an ant that had been eaten upon. A high-risk hunting tactic is spider myrmecophagy. Being attacked by the prey, living close to hazardous prey, being attacked during mating, and having the prey attack and destroy one's eggs if nesting and oviposition take place near ant nests are all risks for myrmecophages (Mathew, 1954). However, a spider that evolves strategies for overcoming an ant's defenses and aggression faces relatively little competition for a nearly unlimited food resource. One study demonstrated that myrmecophagic spiders may actually derive protection against attacks from their own prey: when myrmecophagic, myrmecophilic, myrmecomorphic, and non-ant associating salticids were trapped with ants, the myrmecophagic spiders showed the highest survival rate followed by the myrmecomorphs and myrmecophiles, suggesting that ant associates may signal the ants in such a way that the ants show little aggression towards these spiders (Nelson *et al.*, 2004). The majority of reluctant or indifferent myrmecophages will accept ants in the diet but typically show no specialized hunting behavior for these potentially dangerous predators, whereas the majority of facultative and obligatory myrmecophages have evolved specialized hunting strategies to subdue ants with minimum risk to themselves. Many myrmecophagic spiders, particularly facultative or obligatory predators, live in close proximity to ant colonies, often building their webs directly over nest entrances

or for aging trails or establishing retreats close to or adjacent to nest mounds. In addition to living in close proximity to their prey, these spiders also show specialized hunting behaviors as predicted for stenophagous predators hunting dangerous prey. Instead of jumping at ant prey, many salticids lunge, then quickly bite, release, and bite again, receding each time. Even nonmyrmecomorphic salticids that consume ants use their lungs to hunt ants. The typical stalk and pounce behavior directed toward non-ant prey is very different from this. Myrmecophagic salticids approach ants with far greater caution and are more precise about where they attack their prey; some almost always stand in front of the ant and bite its thorax or petiole.

Conclusion

It has been conclusively shown by research on spider myrmecomorphs that these spiders are Batesian mimics and that the mimicry gives them significant adaptive advantages for survival. Additionally, some studies have examined the evolution of polymorphic and imperfect mimicry. The costs, trade-offs, and limitations associated with the evolution of close physical (and behavioral) similarities to ants should be the main focus of future studies on myrmecomorphic spiders. These elements could significantly affect how accurate the similarity is.

References

Hölldobler, B. and Wilson, E. O. (1990). *The Ants*.
Harvard University Press.

- Benjamin, S. P. (2004). Taxonomic revision and phylogenetic hypothesis for the jumping spider subfamily Ballinae (Araneae, Salticidae). *Zoological Journal of the Linnean Society*, 142(1): 1-82.
- Cushing, P. E. (2012). Spider-ant associations: an updated review of myrmecomorphy, myrmecophily and myrmecophagy in spiders. *Psyche: A Journal of Entomology*, 2012(1): 151989.
- Jackson, R. R. and Pollard, S. D. (2005). Ant-like jumping spiders: Evolutionary convergence with ants. *Journal of Experimental Biology*, 208(11): 1961-1971.
- Nelson, X. J. and Jackson, R. R. (2009). The influence of ants on the mating strategy of a myrmecophilic jumping spider (Araneae, Salticidae). *Journal of Natural History*, 43(11-12): 713-735.
- Mathew, A. P. (1954). Observations on the habits of two spider mimics of the red ant, *Oecophylla smaragdina* (Fabr.). *Journal of the Bombay Natural History Society*, 52: 249-263.
- Nelson, X. J., Jackson, R. R., Pollard, S. D., Edwards, G. B. and Barrion, A. T. (2004). Predation by ants on jumping spiders (Araneae: Salticidae) in the Philippines. *New Zealand Journal of Zoology*, 31(1): 45-56.

Silk's Secret Weapon: Fibroin's Dual Power in Medicine and Tech

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Introduction

For millennia, silk has been synonymous with luxury, draping the bodies of emperors and threading the needles of the world's finest couturiers. Its history is woven into the very fabric of the Silk Road, a testament to its value as a commodity that bridged continents and cultures. However, in the quiet halls of modern laboratories, this ancient material is undergoing a radical renaissance. Scientists are stripping away the lustrous sheen of the textile industry to reveal the raw structural protein beneath: fibroin. No longer just a symbol of wealth, fibroin is emerging as a high-performance biopolymer that is revolutionizing two seemingly disparate fields, regenerative medicine and cutting-edge technology. As researchers uncover its hidden properties, fibroin is proving to be nature's secret weapon, offering a unique duality that synthetic materials struggle to match.

Deconstructing the Thread: The Chemistry of Fibroin

To understand the power of fibroin, one must first look past the smooth texture of a silk scarf. Silk produced by the domestic silkworm, *Bombyx mori*, is a composite material. It consists primarily of two

proteins: fibroin, which forms the structural core, and sericin, a sticky, glue-like coating that holds the filaments together. While sericin has its own applications, it is often removed (a process called degumming) because it can trigger immune responses in some individuals. What remains is pure fibroin, a protein chain composed of amino acids arranged in a highly organized, repetitive sequence. This molecular architecture is the source of fibroin's "superpowers." The protein chains can pack together tightly to form crystalline regions known as beta-sheets. These sheets act like the steel rebar in reinforced concrete, granting the material immense tensile strength and toughness. Conversely, the less organized, amorphous regions provide elasticity. This combination allows fibroin to be incredibly strong yet flexible. Furthermore, researchers have found that by manipulating the processing conditions, they can control the ratio of crystalline to amorphous structures, effectively tuning the material's degradation rate and mechanical properties to suit specific needs (Rockwood *et al.*, 2011). This tunability is the cornerstone of its versatility, allowing a single protein to be molded into porous sponges, transparent films, microscopic spheres, and

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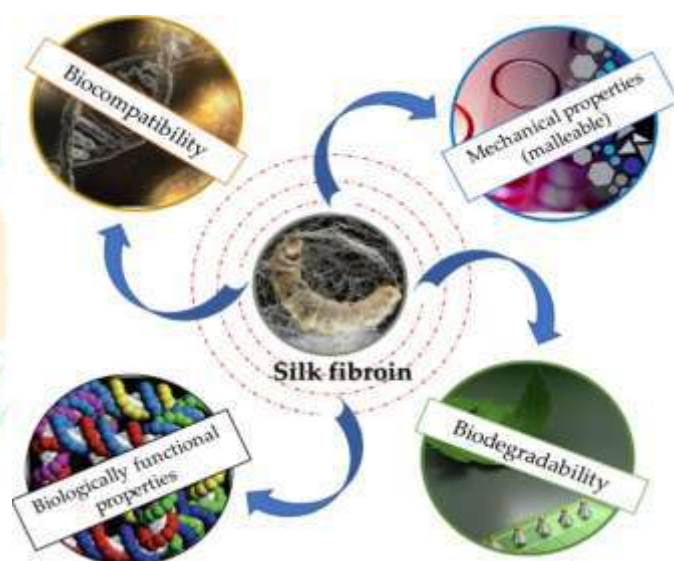
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hydrogels.

The Medical Frontier: A Scaffold for Life

In the realm of biomedicine, the search for the perfect scaffold material is the holy grail of tissue engineering. The body is notoriously picky; it rejects synthetic plastics, creates scar tissue around metals, and degrades many polymers into acidic by products that cause inflammation. Enter fibroin. Its most celebrated attribute is its exceptional biocompatibility. Unlike its counterpart sericin, purified fibroin elicits a negligible immune response, allowing it to coexist peacefully with human tissue. The specific structure of fibroin allows it to support cell adhesion and proliferation. Studies have demonstrated that fibroin scaffolds can support the growth of a wide variety of cell types, including osteoblasts for bone regeneration and fibroblasts for skin repair (Altman *et al.*, 2003). This makes it an ideal candidate for bone tissue engineering. While bone is naturally rigid, it requires a scaffold that can bear load while new tissue grows. Fibroin's mechanical strength matches that of many native tissues, and its porous architecture can be engineered to mimic the trabecular structure of cancellous (spongy) bone. Over time, as the bone heals, the fibroin gradually degrades into non-toxic amino acids, leaving behind only the patient's own regenerated tissue. Beyond structural support, fibroin is revolutionizing drug delivery. One of the significant challenges in pharmaceuticals is maintaining the stability of sensitive biomolecules, such as proteins and vaccines, without refrigeration. Here, fibroin's hydrophobic

nature and crystalline structure provide a protective cocoon. When therapeutic molecules are encapsulated within a fibroin matrix, they are shielded from thermal and chemical degradation. Research has shown that vaccines stabilized in silk films can withstand high temperatures for months, a breakthrough that could transform the logistics of global vaccination campaigns (Pritchard *et al.*, 2012). This dual ability to act as both a structural scaffold and a protective carrier positions fibroin as a cornerstone of future regenerative therapies.



The Technological Frontier: The Rise of Bio-Electronics

While its medical applications are profound, fibroin's migration into the technology sector represents a paradigm shift toward "green" electronics. The electronics industry is currently grappling with a massive crisis: electronic waste. Fibroin offers a tantalizing alternative, a semiconductor substrate that is not only flexible but fully biodegradable. The unique properties of fibroin allow it to serve as an excellent dielectric material (an electrical insulator)

and a substrate for electronic circuits. Its surface can be easily modified to accommodate conductive materials like gold or silicon. This has led to the development of “transient electronics”: devices designed to perform a function for a predetermined amount of time before dissolving completely. In a landmark study, researchers fabricated ultrathin electronics on silk substrates that could dissolve in water, leaving behind only the minimal electronic components which could be recovered or absorbed (Kim *et al.*, 2010). This technology opens the door to biodegradable sensors, temporary security tags, and environmentally friendly consumer gadgets that reduce the burden on landfills.

Perhaps the most sci-fi application of fibroin lies in the field of photonics. By casting fibroin into smooth, transparent films, scientists can mold it into optical waveguides and diffraction gratings. These are components that guide and manipulate light, essential for telecommunications and sensing. Unlike glass or synthetic plastics, silk fibroin films are highly transparent across a broad spectrum, from the ultraviolet to the infrared. This optical clarity, combined with its biocompatibility, has led to the creation of silk-based optical sensors that can be implanted directly into the body. These sensors can monitor oxygen levels or glucose concentrations in real-time, transmitting data via light signals before harmlessly dissolving into the surrounding tissue (Lawrence *et al.*, 2010).

The Intersection: Bio-Integrated Devices

The true magic of fibroin lies in the inter-

section of these two powers: medicine and technology, creating a new class of bio-integrated devices. This is where the boundary between biology and machine begins to blur. Traditional electronic implants, such as pacemakers or neural probes, often cause chronic inflammation because the stiff, inorganic materials rub against soft biological tissue. Fibroin offers a mechanical match that bridges this gap. Fibroin can act as a substrate for these electrodes, allowing them to conform to the brain's surface, reducing immune rejection and improving signal quality. Furthermore, because fibroin is biodegradable, these interfaces can be designed to disappear once their job is done, eliminating the need for surgical removal. This “transient” capability is redefining medical intervention. A silk-based electronic device could be implanted after surgery to monitor for infection and deliver antibiotics on demand. Once the wound is healed, the device dissolves, leaving no trace. This approach reduces the risk of secondary infections and eliminates the psychological and physical burden of device removal. As noted by researchers in the field, the ability to program the lifespan of a medical device through the crystallinity of the silk offers unprecedented control over patient care (Kundu *et al.*, 2013).

Challenges and the Future

Despite the immense promise, the road to widespread fibroin adoption is not without speed-bumps. The primary challenge lies in the standardization of production. “Silk” is not a monolithic

product; its properties vary depending on the silkworm's diet, the extraction process, and the processing methods. Moving from small-batch laboratory success to industrial-scale manufacturing requires rigorous quality control to ensure that medical devices meet regulatory standards. Furthermore, while *B. mori* silk is widely available, the industry is looking toward “recombinant” silk, silk proteins produced by genetically modified bacteria or yeast which allows for greater customization, enabling scientists to engineer silk proteins with specific functions, such as integrating cell-binding motifs directly into the protein chain.

Conclusion

From the ancient looms of China to the sterile cleanrooms of modern biotechnology, silk has traveled a remarkable distance. Fibroin is no longer merely the by-product of a textile trade; it is a sophisticated platform material that challenges our reliance on synthetic polymers. Its dual power lies in its ability to speak the language of biology, supporting cell life and degrading harmlessly, while simultaneously performing the functions of high-tech materials, conducting signals, manipulating light, and providing structural integrity. As we move toward a future that demands sustainable solutions and personalized medicine, fibroin stands ready. It represents a convergence of nature’s evolutionary wisdom and human engineering ingenuity. In the secret architecture of the silk thread, we are finding the keys to healing our bodies and preserving our planet.

References

- Altman, G. H., Diaz, F., Jakuba, C., Calabro, T., Horan, R. L., Chen, J., ... and Kaplan, D. L. (2003). Silk-based biomaterials. *Biomaterials*, 24(3): 401-416.
- Kim, D. H., Viventi, J., Amsden, J. J., Xiao, J., Vigeland, L., Kim, Y. S., ... and Rogers, J. A. (2010). Dissolvable films of silk fibroin for ultrathin conformal bio-integrated electronics. *Nature Materials*, 9(6): 511-517.
- Kundu, B., Rajkhowa, R., Kundu, S. C. and Wang, X. (2013). Silk fibroin biomaterials for tissue regenerations. *Advanced Drug Delivery Reviews*, 65(4): 457-470.
- Lawrence, B. D., Cronin-Golomb, M., Georgakoudi, I., Kaplan, D. L. and Omenetto, F. G. (2010). Bioactive silk protein biomaterial systems for optical devices. *Biomacromolecules*, 11(12): 3211-3219.
- Pritchard, E. M., Dennis, P. B., Omenetto, F. and Kaplan, D. L. (2012). Review physical and biological aspects of silk fibroin matrices as a vehicle for drug delivery. *Biopolymers*, 97(6): 414-427.
- Rockwood, D. N., Preda, R. C., Yücel, T., Wang, X., Lovett, M. L. and Kaplan, D. L. (2011). Materials fabrication from *Bombyx mori* silk fibroin. *Nature Protocols*, 6(10): 1612-1631.

Flora of Ramayana: Exploring Plant Diversity in Valmiki's Epic

Kirti Hari Patil and S. R. Kshirsagar

Introduction

A wealth of information about spiritual, physical, chemical, and biological sciences can be found in the ancient Sanskrit literature of Bharatvarsha. The Vedic literature (Vedas, Puranas, Upanishads, Aranyakas, Shastras, Smrities, Samhitas, Mahakavyas-Ramayana and Mahabharata, Khand-kavyas, etc., written by various sages and hermits who lived in the forests in ancient times) describes a wide range of plant and animal species and their medicinal, economic, cultural, and ecological roles and values for man and nature. The epic poem (Mahakavya) of Bharatvarsha, Shrimad Valmiki Ramayana, tells the story of virtue's quest to eradicate vice. The trip of Shri Rama is known as the Aayana. In Bharatvarsha, we believe that Shri Rama lived in Treta Yug, millennia BC. Today, we are more interested in what the Shrimad Valmikiya Ramayana tells us than in when it was told. Ten thousand years before Lord Rama was born, the scholar Valmiki is thought to have written the Ramayana.

The Ramayana is written in a difficult meter known as Anustup and contains verses known as Shloka in Sanskrit, an ancient Indian language. These lyrics are arranged into distinct chapters

known as Sargas, each of which tells the story of a certain incident or purpose. These chapters or sargas are grouped into books called Kandas where Kanda means the inter-node stem of sugarcane, or also a particular phase of the story or an event in the course of storytelling. The Ramayana, originally written by sage Valmiki, consists of 24,000 shlokas and seven cantos (Kaṇḍas). But it is believed that the Uttara Kanda was not original work of Valmiki. Valmiki had written only 6 Kandas. Because at the end of Yudhha Knada, Valmiki has closed the Ramayana by writing the greatness, result, and importance of listening and reading of the Ramayana.

The Seventh Kanda i.e. the Uttara Kanda was written by the other person. It has been linked by some other person to tarnish the glory of Lord Shri Rama. The Ramayana tells the story of a prince, Rama of the city of Ayodhya in the Kingdom of Kausala, whose consort Sita is abducted by Ravana, the demon-king (Rakshasa) of Lanka. In Sanskrit literature, Valmiki is revered as the harbinger-poet. He is regarded as the first poet, Adi Kavi, who wrote the first epic poem, the Ramayana. He was born Agni Sharma to Pracheta (also called Sumali), a Brahmin from Bhrigu gotra. Legend has it that he once spoke with the renowned sage Narada about his responsib-

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ilities. Agni Sharma started performing penance and chanting the word “Mara,” which means “die,” after being moved by Narada's remarks.

The word changed to “Rama,” the name of the god Vishnu, as he carried out his penance for a number of years. Agni Sharma became known as Valmiki because of the enormous anthills that developed around him. In the Ramayana, the forest in general is described as shanta (calm), madhura (sweet), raudra (anger) and vibhatsa (fearful) which reflect the four sentiments which dominate the entire forest environment (Lutgendorf, 2001). Thick forests are reported in Chitrakoot, Dhandakaranya, Panchavati, Kishkinda (Pampa sarovar), and Lanka. The superiority of nature is reflected in the Ramayana's descriptions. Its reach extends from Sri Lanka to Ayodhya in contemporary Uttar Pradesh. As a result, it provides us with a thorough understanding of the various natural areas that comprise this region. The tropical deciduous forest, the dry and moist deciduous forest, Sri Lanka's evergreen tropical forests, and the alpine region semi-forests (Himalayan) are the four main ecosystems found in the area (Mira Roy, 2005).

Plant / Tree Diversity in Ramayana

Valmiki was familiar with Bharartvarsha's entire topography, including its rivers, mountains, and flora and wildlife. He has described a variety of woodlands with a range of plant species that were present throughout Lord Rama's entire journey from Ayodhya to Lanka. He has described a variety of forest types, including the evergreen tropical forests

of Sri Lanka, the dry and moist deciduous forests of Kishkindha and Rameshwaram, and the tropical dry mixed deciduous forests of Tadka Vana (Malada and Karusha), Chitrakoota, Dandkaranyas (including parts of Madhya Pradesh, Chattisgarh, and Andhra Pradesh), and Panchvati.

Tadka forest: During the Ramayana period, Tadkavan, a holy forest in Maharashtra, India, was significant. During his banishment, Lord Rama is said to have meditated here in search of wisdom and blessings. Encircled by beautiful trees like peepal and banyan, the forest devoted to Shiva was a calm and peaceful place. The region was probably home to sages and hermits who sought enlightenment and practiced tapas. Tree species mentioned in Tadka van (Malad and Karush forests, Rama's first journey with sage Vishvamitra) are Dhav (*Terminalia anogeis-siana*), Ashwakarna (*Dipterocarpus turbinatus*), Arjun (*Terminalia arjuna*), Bel (*Aegle marmelos*), Tendu (*Diospyros melanoxylon*), Padar (*Sterios-permum chelonoides*) and Ber (*Ziziphus mauritiana*) etc.

Chitrakoot forest: The Chitrakoot forest had a thriving environment with of a wide variety of plants and animals during the Ramayana period. Situated on the banks of the Mandakini River, this place was adored for its natural beauty and was considered sacred and tranquil. Here, Lord Rama, Sita, and Lakshmana lived in harmony with the natural world during their eleven-year exile. The three found comfort and refuge in the forest's magnificent trees, glistening streams, and fauna. The tree species found

in Chitrakoot (Kamadgiri) forests as mentioned in Ramayana are Aam (*Mangifera indica*), Jamun (*Syzygium cumini*), Asna (*Terminalia elliptica*), Lodh (*Symplocos racemosa*), Priyal (*Buchanania lanzan*), Panasa (*Artocarpus heterophyllus*), Dhav (*Terminalia anogeissiana*), Palash (*Butea monosperma*), Ankol (*Alangium salviifolium*), Bhavya (*Dillenia indica*), Tinish (*Ougenia oojensis*), Bel (*Aegle marmelos*), Tendu (*Diospyros melanoxylon*), Bans (*Dendrocalamus strictus*), Kasmari (*Gmelina arborea*), Neem (*Azadirachta indica*), Sal (*Shorea robusta*), Varuna (*Crateva adansonii* subsp. *odora*), Mahua (*Madhuca longifolia*), Tilak (*Wendlandia heynei*), Ber (*Ziziphus mauritiana*), Aonla (*Phyllanthus emblica*), Kadamb (*Neolamarckia cadamba*), Bent (*Calamus rotung*), Indrajaui (*Holarrhena pubescens*), Beejak (*Punica granatum*), Putrajivak (*Putranjiva roxburghii*), Punnaag (*Calophyllum inophyllum*), Bhojpatra (*Betula utilis*), Bhilava (*Semecarpus anacardium*), Malati (*Jasminum humile*), Champa (*Jasminum officinalis*), Utpal (*Nelumbo nucifera*) with other flowering, fruiting and shade giving trees.

Panchvati forest: The Panchvati forest, which is close to present-day Nashik, was a rich and dynamic ecology during the Ramayana period. Because of its spiritual significance and natural beauty, the woodland was considered a hallowed place. Here, Lord Rama, Sita, and Lakshmana lived in a hermitage constructed of leaves and twigs for a number of years while they were in exile. Five sacred trees that represented the five elements of nature

were found at Panchvati: Ashwatha, Bilva, Amalaki, Pipal, and Banyan. The Godavari River flowed close by, offering comfort and sustenance, and the forest was filled with wildlife. Shurpanakha, Ravana's sister, met Rama and Lakshmana here, setting up a crucial scene in the epic.

Pampa Sarover: The shrubs, climbers and trees found around Pampa Sarover, Kishkindha and Prasravanagiri mountain are Palash (*Butea monosperma*), Malati (*Aganosma heynei*), Mallika (*Jasminum sambac*), Karveer (*Nerium oleander*), Ketaki (*Pandanus odorifer*), Sindhuvar (*Vitex negundo*), Vasanti (*Jasminum officinale*), Madhvi lata (*Hiptage benghalensis*), Chilbil (*Holoptelea integrifolia*), Mahua (*Madhuca longifolia*), Bent (*Calamus rotung*), Molsiri (*Mimusops elengi*), Champa (*Magnolia champaca*), Tilak (*Wendlandia heynei*), Nagkeshar (*Calophyllum inophyllum*), Padmak (*Prunus cerasoides*), Lodhra (*Symplocos racemosa*), Ankol (*Alangium salviifolium*), Kurantak (*Barleria prionitis*), Churnak (*Bombax ceiba*), Parbhadrak (*Erythrina variegata*), Aam (*Mangifera indica*), Patli (*Steriospermum chelonoides*), Kovidar (*Bauhinia variegata*), Muchukund (*Pterospermum acerifolium*), Arjun (*Terminalia arjuna*), Ketak (*Strychnos potatorum*), Uddhalak (*Cordia dichotoma*), Shirish (*Albizia lebbek*), Shisham (*Dalbergia sissoo*), Dhav (*Terminalia anogeissiana*), Semal (*Bombax ceiba*), Lal kurvak (*Barleria cristata*).

Plant used in Setu Bandh: Plants used in the Setu bandh (Construction of bridge from Rameshwar to Lanka on sea) are Sal (*Shorea robusta*), Ashwakarna

(*Dipterocarpus turbinatus*), Dhav (*Terminalia anogeissiana*), Bans (*Bambusa bambos*), Kutaj (*Holarrhena pubescens*), Arjun (*Terminalia arjuna*), Tal (*Borassus flabellifer*), Tilak (*Wendlandia heynei*), Tinish (*Ougeinia oojeinensis*), Bel (*Aegle marmelos*), Chhitwan (*Alstonia scholaris*), Karnikar (*Pterospermum ascerifolium*), Aam (*Mangifera indica*), Ashok (*Saraca asoca*), Anar (*Punica granatum*), Nariyal (*Cocos nucifera*), Baheda (*Terminalia bellirica*), Karir (*Capparis decidua*), Bakul (*Mimusops elengi*) and Neem (*Azadirachta indica*) etc.

The fact that the locations where Valmiki detailed the existence of plants in the Ramayana are still present today is somewhat unexpected. This demonstrates that sage biogeography and biodiversity of all of Bharatvarsha were well understood by Valmiki. The Ramayana is a valuable source of knowledge, providing information on wild creatures, birds, insects, and plants in addition to mammals like bears and monkeys. These species' identification could be a very useful tool for locating those locations and recording historical events. Although Balapure *et al.* (1987) and Amrithalingam (2013) provided a thorough description of the plants mentioned in the Valmiki Ramayana, their writings listed the plants according to their Sanskrit synonyms. For example, the synonyms of lotus, such as Jalaj, Pankaj, Padm, Ambuj, Saroj, etc. were listed in different numbers, making it impossible to determine the precise number of plants mentioned in the Ramayana. The Ramayana mentions Sandhani,

Suvarnakarni, Mritsanjivani, and Vishalyakarni as medicinal herbs that were utilized to heal injured Lakshmana. A number of researcher attempted to identify *Selaginella bryopteris* (L.) Baker as Sanjivani (Ganeshaiah *et al.* 2009, Antony and Thomas, 2011), but Sandhani, Suvarnakarni, Vishalyakarni, and real Mritsanjivani remain dreadful mysteries. Certain flora, such as Ashwakand (a tuber), Neel Ashok (trees), and Satyopvachan (a holy tree), are still unknown.

Conclusion

An enormous amount of amazing scientific knowledge about nature, natural resources, and biotic resources may be found in the ancient Sanskrit Vedic literature of Bharatvarsha, which includes the Vedas, Puranas, Upanishads, Shastras, Samhitas, Smritis, and Epics. However, the majority of ancient literature was written in Sanskrit by sages and hermits, which is difficult for the average person to read and comprehend. We can say with firmness that the sage Valmiki was well-versed in the phytogeography of that era of Bharatvarsha after carefully reading the Valmiki Ramayana's depiction of plant diversity. He knew everything there was to know about the many kinds of forests, vegetation, animals, rivers, mountains, etc. With a few exceptions, the flora he named in the regions of Chitrakoot, Dandakarnya, Panchvati, and Lanka are still present. For instance, the Ramayana mentions "Bhavya" (*Dillenia indica*), "Bent" (*Calamus rotung*), "Punnag" (*Calophyllum inophyllum*), and "Bhojpatra" (*Betula utilis*) in the Chitrakoot forest,

but these plants are no longer extant.

References

- Amirthalingam, M. and Reddy, P. S. (2013). *Plant and Animal Diversity in Valmiki's Ramayana*. CPR Environmental Education Centre.
- Antony, R. and Thomas, R. (2011). A mini review on medicinal properties of the resurrecting plant *Selaginella bryopteris* (Sanjeevani). *International Journal of Pharmacy & Life Sciences*, 2(7).
- Balapure, K. M., Maheshwari, J. K. and Tandon, R. K. (1987). Plants of Ramayana. *Ancient Science of Life*, 7(2): 76-84.
- Ganeshiah, K. N., Vasudeva, R. and Shaanker, R. U. (2009). In search of Sanjeevani. *Current Science*, 484-489.
- Lutgendorf, P. (2000). City, forest, and cosmos: Ecological perspectives from the Sanskrit epics. *Hinduism and Ecology*, 269-290.
- Roy, M. (2005). Environment and Ecology in the Ramayana. *Indian Journal of History of Science*, 40(1): 9-29.

Weed: An Alternate Energy Source

Madhab Kumar Datta

Introduction

Weeds are invasive or unwanted plants that are non-native to the ecosystem which grow along with food crops threatening the food security, health or economic development and biodiversity (Bajwa *et al.*, 2016). They are competitive, able to persist and grow under any unfavorable conditions with high reproducing capacity and seed bank quality. India being a temperate country has diverse resources of plants grown in different crop and non-croplands. Weeds grow everywhere consuming the nutrients, soil moisture, space, etc., meant for food crops and thus ultimately affect the crop productivity adversely. Practically, weeds are plants that need to be prevented, controlled or managed to economically benefit an agriculturist. Typically, the principal weed management protocol would be cultural and mechanical in nature, focusing on prevention, crop rotation and cultivation. To have an operative weed management program, one should consider the pest problems, soil quality, capital investment, market, climate, manpower and labour. An efficient weed management system will benefit from an understanding of the weed control tactics based on all these criteria. One of the main things limiting production is inadequate weed control for the majority of food crops. According to Bridges' 1992 assessment,

weeds are prevalent throughout 405 million hectares of range and pasture and 196.27 million hectares of farmland in the United States. The weed management program has drawn the attention of researchers worldwide because to this fact. When it comes to chemical and mechanical weed control methods, there are worries that they will quickly adapt and lessen the effects. According to Hicks *et al.* (2018), when herbicides are applied frequently, weeds develop resistance to them. As a result, a few hard-to-control weed species now dominate agricultural landscapes. According to a number of studies, weeds can be utilized as compost, green manure, biocontrol agents, and soil ameliorators (Rashid *et al.*, 2008). These applications could enhance the biological, chemical, and physical characteristics of the soils as well as produce significant amounts of energy. Weeds from the fields are readily available and provide a substantial contribution as an alternative energy source. Ample availability of weeds from the fields contributes significantly as alternative energy source. There are two main processes involved under energy recovery from plant source (biomass), the thermochemical process and biological process (biomethanation process). Thermo-chemical process is better choice of energy recovery over the biological process due to its cost-

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effectiveness. But in developing countries like India, a cost-effective thermochemical process of energy recovery is still not a preferred choice due to its low calorific value.

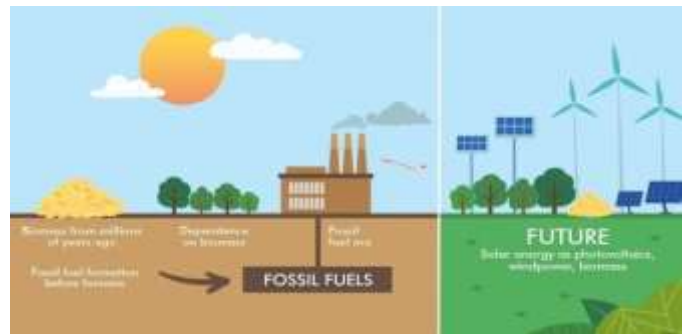
Approaches for bioenergy production from aquatic weeds

The physical attributes e.g. high cellulose, starch and lipid content of aquatic weeds make them a promising bioenergy feedstock and they can be easily converted into multiple forms of energy like bioethanol, biodiesel, biohydrogen and biomethane through the implementation of appropriate processing technologies. The technologies for converting aquatic biomass into bioenergy can be divided into four major categories, viz., biochemical conversion, anaerobic digestion, dark fermentation and ethanol fermentation.

Anaerobic digestion: A common method for producing biogas is anaerobic digestion, which uses microorganisms in anaerobic conditions to break down organic waste and produce biogas as a byproduct. Compared to other biomass conversion technologies, it requires less capital investment, making it a more cost-effective approach (Rao *et al.*, 2010). Because of their high carbohydrate content and ideal C/N ratio, a variety of aquatic weeds are being successfully employed for biogas production.

Acidogenic fermentation: Anaerobic digestion includes acidogenic fermentation, which uses hydrogen-producing culture to transform organic materials into volatile fatty acids (VFAs) and hydrogen. *Clostridium* and *Enterobacter* are the most

well-known bacterial species that produce biohydrogen. Because of its gentle operating conditions, low energy requirements, and high hydrogen production rates in comparison to photofermentation, it is regarded as the most straightforward and cost-effective approach for producing biohydrogen.



Ethanol fermentation: Due to their low lignin content and light pretreatment requirements, aquatic weeds are currently chosen over lignocellulosic crops for the generation of ethanol, making cellulosic ethanol manufacturing more affordable.

Thermochemical conversion: Thermochemical conversion includes the thermal decomposition of biomass into liquid, gaseous and solid fuel products. The process of pyrolysis involves subjecting the biomass fuel to pressured, anaerobic conditions at high temperatures (less than 430°C). Pyrolysis processes produce a solid residue known as biochar and a liquid fuel known as bio-oil. Biochar is used for long-term carbon sequestration and soil amendment, whereas bio-oil is a synthetic fuel that can be used in place of petroleum.

Supercritical water gasification: A new method for recycling wet biomass (70-95% moisture) to produce synthesis gas with a higher hydrogen content is supercritical water gasification. Compared to other

traditional processes like thermal gasification, pyrolysis, anaerobic digestion, and liquefaction, its conversion efficiency is often higher. This method works best for producing bioenergy from aquatic weeds because of their high moisture content (70-80%) (Matsumura *et al.*, 2002).

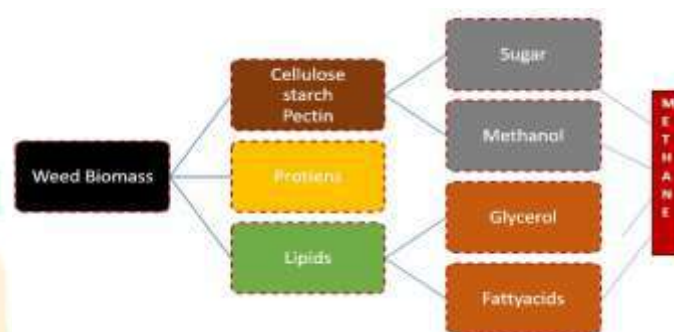
Biogas Production from the different Weeds

Water Hyacinth (*Eichhornia crassipes*): Water hyacinth contains cellulose, hemicellulose, and starch with a low lignin level, making it an efficient fuel for biogas production. Water hyacinth's cellulose content makes it a desirable feedstock for biogas production because it is widely available and can recover even after suffering harm (Barua *et al.*, 2019). Water hyacinth can be used to generate biogas by anaerobic digestion because of its high water content and suitable C/N ratio.

Water Lettuce (*Pistia stratiotes*): *Pistia* produced a high volume of CO₂ and significant amounts of propionic, butyric, isobutyric, valeric and isovaleric acids. *Pistia stratiotes* and *Typha latifolia* are used as feedstock in High Solid Anaerobic Digesters (HSADs) by Varun and Chandran (2017). According to the experiment's findings, *Pistia stratiotes* and *Typha latifolia* produced cumulative biogas yields of 17,570 ml and 14,175 ml, respectively.

Common duckweeds (*Lemna perpusilla*): Duckweed being a lignocellulosic biomass with an adequate concentration of lignin and cellulose, requires maximum time to break into unstable carbon moieties and hence proved to be an ambassador for methanogenesis. An anaerobic digester, or batch and

semi-continuous digestion from iron-rich duckweed (*Lemna minor*), was used in a study by Clark *et al.* (1996) to demonstrate biogas enhancement on a laboratory scale. In this study, it took 40 days for methane production to reach the top of batch digestion without duckweed, but it only took 15 days with duckweeds added, and the semi-continuous digester produced 44% more gas. Therefore, this study provides proof that anaerobic digestion of duckweed is a useful method for producing biogas.



Congress grass (*Parthenium hysterophorus*):

Parthenium has attained a key position in terms of weed management programs among the different weeds that pose an ecological and economic threat worldwide. Therefore, a great deal of research was done on the effects of *P. hysterophorus* on the nation's economy, weed control, *P. hysterophorus* as a possible feedstock for the anaerobic digestion process, its methane potential, batch anaerobic systems, pretreatments, co-additives, inoculums substrate (I/S) ratio, and primarily the metagenomic analysis of the microbiome involved. Utilizing weeds on a large scale might be an appealing and economically significant alternative to effective weed management. Despite being a weed, the plant has been shown to have several positive pharmacolo-

gical and therapeutic properties in addition to industrial and other uses.

Conclusion

Weed biomass offers greater ecological and economic viability as a substrate for alternative energy sources, despite the fact that organic matter is widely available. Different pretreatment techniques address the difficulties in the bacteria found in the weeds using biomass that is not readily available. According to a reputable study, weed biomass treated with this kind of pretreatment produces a large amount of methane. Other than uprooting weeds for biogas use, replacing them with food crops and native species, lowering floods, enhancing soil quality, etc., using weeds as a possible source of alternative energy has significant co-benefits. Therefore, the main goal of using weeds for biogas production is to improve ecological and economic aspects worldwide.

References

- Hicks, H. L., Comont, D., Coutts, S. R., Crook, L., Hull, R., Norris, K., ... and Freckleton, R. P. (2018). The factors driving evolved herbicide resistance at a national scale. *Nature Ecology & Evolution*, 2(3): 529-536.
- Varun, P. and Chandran, S. S. (2017, December). Sustainable utilization of some noxious aquatic weeds by energy recovery using high solid anaerobic digesters. In *2017 International Conference on Technological Advancements in Power and Energy (TAP Energy)* (pp. 1-5). IEEE.
- Bajwa, A. A., Chauhan, B. S., Farooq, M., Shabbir, A. and Adkins, S. W. (2016). What do we really know about alien plant invasion? A review of the invasion mechanism of one of the world's worst weeds. *Planta*, 244(1): 39-57.
- Rashid, H., Khan, M. A., Amin, A., Nawab, K., *et al.* (2008). Effect of *Parthenium hysterophorus* L., root extracts on seed germination and growth of maize and barley. *The Americas Journal of Plant Science and Biotechnology*, 2(2): 51-55.
- Rao, P. V., Baral, S. S., Dey, R. and Mutnuri, S. (2010). Biogas generation potential by anaerobic digestion for sustainable energy development in India. *Renewable and Sustainable Energy Reviews*, 14(7): 2086.
- Matsumura, Y. (2002). Evaluation of supercritical water gasification and biomethanation for wet biomass utilization in Japan. *Energy Conversion and Management*, 43(9-12): 1301-1310.
- Barua, V. B., Rathore, V. and Kalamdhad, A. S. (2019). Anaerobic co-digestion of water hyacinth and banana peels with and without thermal pretreatment. *Renewable Energy*, 134: 103-112.
- Clark, P. B. and Hillman, P. F. (1996). Enhancement of anaerobic digestion using duckweed (*Lemna minor*) enriched with iron. *Water and Environment Journal*, 10(2): 92-95.

Ophiocordyceps sinensis: The Himalayan Caterpillar Mushroom Species More Worth than Gold

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Introduction

The fungus *Cordyceps* spp. is remarkably well known for its medicinal properties as well as potent chemical compounds. In fact, it has been used as remedies for various diseases by local folks of Tibet for over 500 years. The word *Cordyceps* was derived from Greek expression ‘kordyl’ and Latin phrase ‘ceps’, meaning ‘club’ and ‘head’, which describing the fungus appearance. There are relatively 500 species of *Cordyceps* spp. identified to date, among which *Ophiocordyceps sinensis* (syn. *Cordyceps sinensis*) being the most expensive due to its rarity. High on the windswept plateaus of the Himalayas, where the air is thin and the temperatures plummet well below freezing, a peculiar biological drama unfolds. It involves a ghost moth larva, buried beneath the soil, and a parasitic fungus that consumes it from the inside out. The result of this macabre interaction is *Ophiocordyceps sinensis*, colloquially known as the caterpillar mushroom or Yartsa gunbu. While its biological origins sound like the plot of a science fiction horror film, its economic reality is staggering. Prized for centuries in Traditional

fungus has transcended its status as a medicinal remedy to become a global commodity with a price tag that rivals and often surpasses, that of gold.

Nature’s Macabre Masterpiece

To understand the value of *O. sinensis*, one must first understand the rarity and difficulty of its creation. The fungus is endemic to the alpine meadows of the Tibetan Plateau and the high Himalayas of Nepal, Bhutan, and India, typically found at altitudes between 3,000 and 5,000 meters. The life cycle begins when fungal spores infect the larvae of ghost moths (Genus *Thitarodes*) while they hibernate underground. Once infected, the fungus slowly consumes the host’s internal organs during the winter months, preserving the exoskeleton. As the temperature rises in the spring, a stalk-like fruiting body bursts forth from the head of the mummified caterpillar, pushing its way through the soil to release spores. This transitional form, half animal, half fungus: is the “winter worm, summer grass” described in ancient texts. The specific environmental conditions required for this lifecycle are incredibly precise, making natural occurrence the

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only viable source of supply; despite decades of research, commercially viable artificial cultivation remains largely elusive, cementing the species' status as a wild, limited resource (Winkler, 2008).



A Pillar of Traditional Medicine

The astronomical value of the caterpillar fungus is rooted in its long history within Traditional Chinese Medicine (TCM) and Tibetan Medicine. Known in Tibetan as Yartsa gunbu (summer grass, winter worm), it has been used for centuries to treat a myriad of ailments, ranging from fatigue and respiratory diseases to kidney and liver ailments. Historically, it was reserved for royalty and the elite, believed to restore vitality and promote longevity. Modern pharmacological interest has sought to validate these traditional claims. Research has identified bioactive compounds within the fungus, most notably cordycepin and polysaccharides. Studies suggest that *O. sinensis* possesses potent immunomodulatory, anti-inflammatory, and anti-tumor properties. Furthermore, it has gained a

reputation in the athletic world for its potential to enhance stamina and oxygen utilization, attributed to its ability to improve the body's production of adenosine triphosphate (ATP) (Yue *et al.*, 2013). While clinical trials are still ongoing to fully map its efficacy, the convergence of ancient wisdom and modern science has bolstered its reputation as a “superfood,” driving demand to unprecedented levels.

The Economics of “Soft Gold”

In the last two decades, the market for *O. sinensis* has exploded, transforming the economy of the Tibetan Plateau. The fungus is traded by weight, and in peak seasons, top-grade specimens have sold for prices exceeding \$100,000 per kilogram, effectively making it more expensive than gold bullion. This “soft gold” rush has become the primary source of income for millions of people living in remote rural areas of Tibet and Nepal. For many harvesters, the annual collection season offers a financial lifeline. The income generated from a successful harvest can account for a significant portion of a household's annual revenue, funding education, healthcare, and infrastructure in regions where economic opportunities are otherwise scarce. However, this economic boom is a double-edged sword. The high stakes have led to a highly commodified market where middlemen and large pharmaceutical companies capture a significant share of the profits, while the actual harvesters bear the physical risks of high-altitude foraging. Nevertheless, the economic footprint of the fungus is unde-

niable, creating a unique socio-ecological system where the livelihoods of entire communities depend on the delicate balance of a parasitic lifecycle (Winkler, 2010).

Ecological Peril and Sustainability

The immense pressure to harvest *O. sinensis* has placed a severe strain on the species and its fragile alpine ecosystem. The phenomenon of the “tragedy of the commons” is palpable here. As demand rises, harvesters are venturing into the fields earlier in the season, often before the fungus has had a chance to mature and release its spores. This premature harvesting disrupts the reproductive cycle, leading to a noticeable decline in population density over the years. Furthermore, the methods of extraction can be damaging. The digging process disturbs the thin, fragile topsoil of the plateau, accelerating erosion and damaging the pasturelands essential for the region's livestock. Conservationists warn that if current harvesting trends continue unchecked, the species faces the risk of functional extinction in the wild. The sensitivity of the fungus to climate change further exacerbates these risks; rising temperatures and shifting snow lines are altering the precise microclimates required for the fungus and the moth larvae to thrive (Hopping *et al.*, 2018). The loss of *O. sinensis* would not only represent a collapse in biodiversity but would also trigger a socio-economic crisis for the region's dependent communities.

Innovation and the Future

Faced with the threat of overharvesting and

supply constraints, the scientific community has intensified efforts to cultivate the fungus or produce its key compounds synthetically. While growing the complex *O. sinensis* fruiting body in a lab remains difficult, scientists have successfully fermented the mycelium, the vegetative part of the fungus in bioreactors. This cultured mycelium, often marketed as Cs-4, contains many of the same bioactive compounds found in the wild product. Biotechnological advances are also focusing on the synthesis of specific compounds like cordycepin and adenosine through heterologous expression systems. Recent genomic studies have mapped the biosynthetic pathways of the fungus, opening the door for engineered production in more tractable microbial hosts, such as yeast or *E. coli* (Li *et al.*, 2011). These innovations aim to democratize the health benefits of the fungus, making them accessible at a fraction of the cost and without the ecological toll of wild harvesting. However, the wild fungus retains a mystique and cultural value that cultured alternatives cannot yet replicate. In the eyes of many consumers in China and Southeast Asia, the wild-harvested “whole organism” is considered superior in potency and energetic properties, ensuring that the demand for the natural product remains high despite the availability of cheaper substitutes.

Regulatory Challenges and Counterfeits

The high value of *O. sinensis* has inevitably spawned a rampant black market rife with adulteration and counterfeiting. Unscrupulous sellers often insert lead wires or pins into the body of the

fungus to increase its weight, a practice that poses serious health risks to consumers. In other instances, similar-looking but chemically inactive fungal species are sold as the genuine article. Recognizing the economic importance and the conservation needs of the species, governments in the region have attempted to implement regulations. In China, the fungus is classified under the “Key Protected Wild Medicinal Materials” category, and local authorities have attempted to impose harvesting bans and seasonal restrictions. However, enforcement is difficult in the vast, remote expanses of the Himalayas. The challenge for policymakers is to find a balance between sustaining the lucrative trade that supports local economies and preserving the biological resource that underpins it (Cannon *et al.*, 2009).

Conclusion

O. sinensis stands as a unique intersection of biology, economy, and culture. It is a parasite that acts as a tonic, a humble fungus that dictates the fortunes of nations, and a natural resource that is being loved to death by its consumers. Its story is a microcosm of the modern relationship between humanity and nature: a relentless pursuit of valuable resources, often at the expense of the very systems that sustain them. As the price of this “Himalayan gold” continues to climb, the need for sustainable management becomes urgent. The future of *O. sinensis* hinges on a dual approach: rigorous conservation to protect its fragile habitat and continued scientific innovation to provide viable, lab-grown

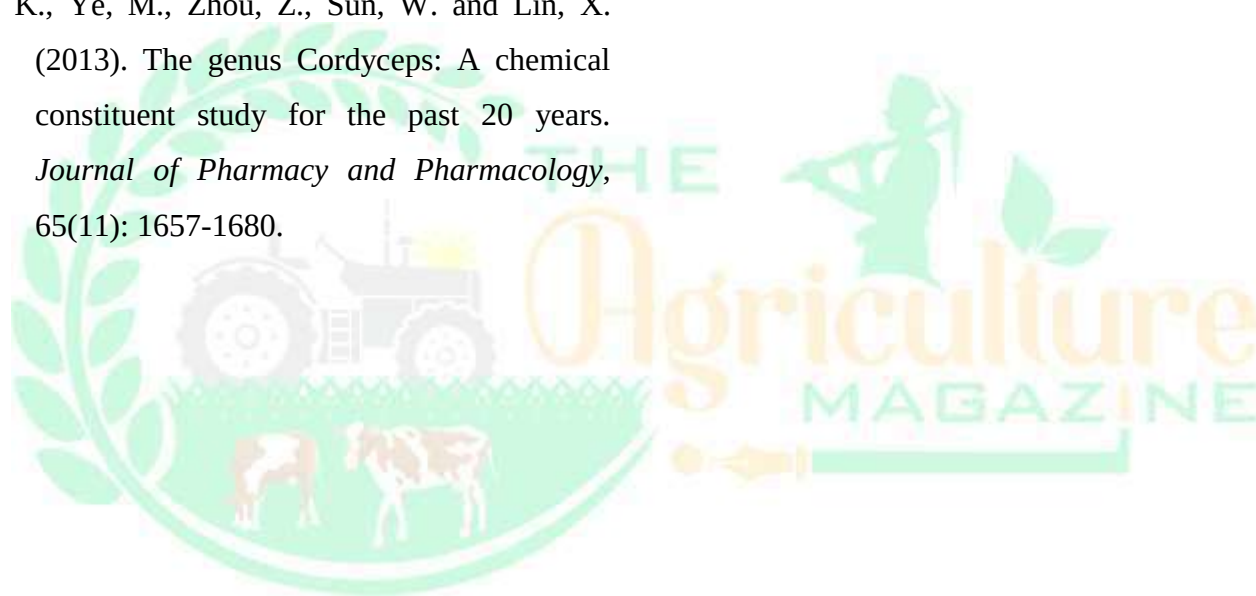
alternatives. Only by decoupling the medicinal benefits from the wild harvest can we ensure that this miraculous organism continues to thrive on the roof of the world, rather than existing only as a memory in the annals of medicine.



References

- Cannon, P. F., Hywel-Jones, N. L., Maczey, N., Norbu, L., Samdup, T. and Lhendup, P. (2009). Steps towards sustainable harvest of *Ophiocordyceps sinensis* in Bhutan. *Biodiversity and Conservation*, 18(9): 2263-2281.
- Hopping, K. A., Knapp, A. K., Dorji, T. and Klein, J. A. (2018). Warming and land use change concurrently erode ecosystem services in Tibet. *Global Change Biology*, 24(5): 2071-2086.
- Winkler, D. (2010). Caterpillar fungus (*Ophiocordyceps sinensis*): Production, sustainability, and the Tibetan pastoralist economy. *Proceedings of the 3rd International Symposium on Fungi*, 1-11.

- Li, Y., Wang, X. L., Jiao, B. and Li, X. (2011). Structural elucidation and anticancer activity of a water-soluble polysaccharide from *Ophiocordyceps sinensis*. *International Journal of Biological Macromolecules*, 48(4): 575-580.
- Winkler, D. (2008). Yartsa gunbu (*Cordyceps sinensis*) and the fungal commodification of Tibet's rural economy. *Economic Botany*, 62(3): 291-305.
- Yue, K., Ye, M., Zhou, Z., Sun, W. and Lin, X. (2013). The genus *Cordyceps*: A chemical constituent study for the past 20 years. *Journal of Pharmacy and Pharmacology*, 65(11): 1657-1680.



Smart Farming: The Rise of Drones, AI and IoT in Agriculture

Marwan Reddy Chinnam and Manda Sai Krishna

Introduction

Agriculture is rapidly shifting toward digitalization in response to rising global food demand, sustainability concerns and technological advancement (FAO, 2019). With population growth intensifying pressure on production systems, farmers must achieve higher yields using limited inputs. Conventional methods are gradually giving way to precision-oriented approaches that enhance efficiency and adaptability. Modern farming integrates artificial intelligence, Internet of Things devices, and robotics to monitor crop conditions, manage resources effectively, and maintain soil integrity (Liakos *et al.*, 2018). Data-driven tools analyze extensive datasets to support informed decision-making, while sensor networks continuously track environmental variables to optimize crop performance. Automated machinery handles repetitive operations, lowering labor dependency and increasing output. Beyond productivity gains, these innovations contribute significantly to environmental protection. Precision techniques enable targeted application of water, fertilizers, and pesticides, minimizing waste and ecological damage (Gebbers and Adamchuk, 2010). Predictive analytics help anticipate pest outbreaks and climatic variations, enabling timely interventions. Soil health management is strengthened through advanced diag-

nostics and controlled use of inputs, ensuring long-term fertility.

AI in Precision Agriculture

Artificial intelligence (AI) is a central driver of precision agriculture, enabling data-oriented management that improves productivity, resource efficiency, and sustainability (Liakos *et al.*, 2018). By integrating advanced analytics with automation, AI systems process large, heterogeneous datasets and deliver real-time, context-specific recommendations. These capabilities allow farmers to optimize operations across the production cycle, from field preparation to post-harvest handling.

Machine Learning and Predictive Analytics

Machine learning has significantly advanced agricultural forecasting and strategic planning. By leveraging historical records and real-time inputs, predictive models anticipate pest outbreaks, disease incidence, and yield fluctuations (Kamilaris and Prenafeta-Boldú, 2018). Such insights support proactive interventions, reducing risk and enhancing output stability. AI tools also refine decisions on sowing and harvesting by considering variables such as soil characteristics, crop phenology, and weather projections. This improves scheduling precision and minimizes resource wastage. In addition, machine learning plays a vital role in yield estimation. Algorithms integrate climatic trends, soil properties,

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Table 1: Comparison of AI-based Image Processing Techniques in Precision Agriculture

Technique	Application Areas	Advantages	Limitations	Accuracy Rate (%)
Convolutional Neural Network (CNN)	Weed detection, disease identification	High accuracy, automatic feature extraction	Requires large datasets, computationally intensive	90-98
Support Vector Machine (SVM)	Crop classification, pest detection	Effective with small datasets, robust	Less effective with large, noisy datasets	85-92
Random Forest (RF)	Yield prediction, soil analysis	Handles high-dimensional data, fast	Prone to overfitting, less interpretable	80-90
K-Nearest Neighbour (KNN)	Crop monitoring, nutrient deficiency detection	Simple implementation, no training phase	Sensitive to noisy data, slow with large datasets	78-85
Deep Belief Networks (DBN)	Disease forecasting, climate impact analysis	Learns complex representations, adaptable	High computational cost, requires fine-tuning	88-95
Recurrent Neural Networks (RNN)	Temporal crop growth monitoring	Effective for sequential data, captures time dependencies	Training complexity, vanishing gradient issue	87-93
Generative Adversarial Networks (GANs)	Data augmentation, anomaly detection	Generates synthetic data, improves robustness	Difficult training process, unstable models	85-90

and past productivity data to generate accurate forecasts. These predictions enable efficient allocation of inputs like fertilizers and pesticides, ensuring they are applied only when necessary. Remote sensing platforms, including drones and satellites, further enhance these models by supplying high-resolution imagery. Analytical systems detect early signs of crop stress or disease, allowing timely corrective measures and preventing large-scale losses.

Image Processing and Remote Sensing

AI-enabled image analysis and remote sensing technologies have transformed field monitoring. High-resolution images captured through aerial and ground-based systems are processed to evaluate crop health, soil conditions, and pest dynamics (Zhang and Kovacs, 2012). One critical application is precision weed control, where computer vision systems distinguish crops from weeds and guide targeted herbicide application. This selective approach reduces chemical usage, lowers environmental contamination, and cuts input costs.

AI also facilitates accurate soil moisture assessment through multispectral and infrared imaging. By analyzing spatial variations in water content, these systems provide real-time irrigation recommendations, ensuring optimal water use and preventing over-irrigation. Disease diagnostics is another key area where image-based AI models compare visual patterns in plants to identify infections at early stages. Early detection limits crop damage and reduces unnecessary pesticide application, contributing to both economic and ecological benefits.

AI-assisted Decision Support Systems

AI-driven decision support systems (DSS) integrate diverse data streams including sensor outputs, satellite imagery, and meteorological information to guide farm management (Kamilaris and Prenafeta-Boldú, 2018). These platforms generate recommendations on crop rotation, nutrient management, and optimal planting windows. Continuous learning from incoming data enhances their predictive accuracy, enabling adaptive responses to changing environmental conditions.

Precision fertilization is a prominent application of such systems. By analyzing soil nutrient profiles, AI models prescribe exact input requirements tailored to specific crops and field conditions. This targeted nutrient management prevents overuse, mitigates soil degradation, and reduces the risk of water pollution. Beyond field-level decisions, AI-supported DSS also improve post-harvest processes and supply chain efficiency. Predictive analytics help align production with market demand, optimize distribution, and minimize losses during storage and transport.

IoT in Smart Agriculture

The Internet of Things (IoT) has emerged as a transformative force in modern agriculture, significantly reshaping traditional farming practices (Wolfert *et al.*, 2017). By integrating interconnected devices, wireless communication systems, and cloud-based platforms, IoT enables farmers to remotely observe and control critical agronomic variables. As a result, farmers can optimize resource utilization, reduce wastage, and make informed, data-driven decisions that enhance productivity and long-term sustainability. A major advantage of IoT in agriculture lies in its ability to automate routine monitoring and management operations. Field-based sensors and devices consistently collect and transmit data, minimizing the reliance on manual field inspections. Additionally, IoT systems facilitate early identification of risks such as pest attacks, disease emergence and nutrient imbalances, enabling timely preventive measures. Enhanced communicat-

ion between agricultural machinery further ensures efficient and synchronized farm operations. Beyond operational efficiency, IoT contributes significantly to sustainable farming by improving the management of key inputs. Sensor-derived data allows precise scheduling of irrigation, optimized fertilizer application, and reduced energy consumption. When combined with artificial intelligence, IoT systems gain predictive capabilities, empowering farmers to anticipate challenges and take proactive actions that increase yield while minimizing environmental impact (Wolfert *et al.*, 2017).

IoT-Based Sensor Networks: Sensor networks driven by IoT technologies play a crucial role in advancing smart farming systems. These networks provide continuous measurements of parameters such as soil moisture, temperature, humidity, and nutrient availability. By enabling real-time environmental monitoring, they support informed decision-making and precise resource allocation (Wolfert *et al.*, 2017). Farmers can remotely track field conditions and respond promptly to changing scenarios, improving both productivity and efficiency. Integration with cloud platforms and AI-powered analytics further enhances the interpretation of collected data, delivering actionable insights for precision agriculture. Wireless sensor networks ensure seamless data transmission across devices. For instance, fluctuations in soil moisture detected by sensors can trigger targeted irrigation practices. Similarly, temperature and humidity sensors can alert farmers to impending weather changes, allowi-

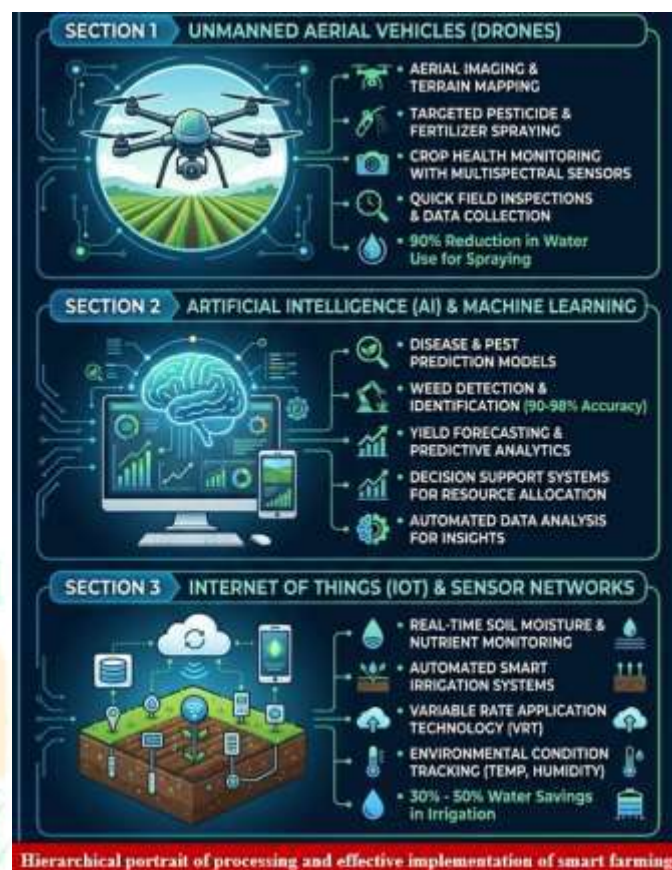
ng them to implement protective measures.

Smart Irrigation Systems: IoT-enabled irrigation systems are designed to deliver water efficiently based on real-time field conditions, thereby minimizing wastage and preventing excessive irrigation (Gebbers and Adamchuk, 2010). These systems incorporate soil moisture sensors, weather data inputs, and automated control mechanisms to regulate water application. Advanced irrigation setups, including smart sprinklers and drip systems, adjust water supply according to crop requirements and soil conditions. Cloud-based analytics process sensor data to generate precise irrigation recommendations, resulting in improved water-use efficiency and cost savings. These technologies not only enhance crop yield but also promote sustainable water management practices.

Robotics and Automation in Agriculture

The incorporation of robotics and automation has fundamentally improved agricultural efficiency, precision, and labor management (Liakos *et al.*, 2018). Automated systems such as self-operating machinery, precision planting tools, and soil management devices enhance productivity while reducing dependence on manual labor. These technologies also help address labor shortages and improve overall farm economics. Modern robotic systems utilize artificial intelligence and machine learning algorithms to adapt dynamically to environmental conditions and crop needs. When integrated with IoT infrastructure, they enable optimized input usage, reducing reliance on fertilizers and pesticides.

Additionally, automation contributes to environmental sustainability by lowering carbon emissions and minimizing soil compaction.



Conclusion: Securing the Future of Food

Smart Farming represents a paradigm shift from “maximum input” to “maximum efficiency.” By leveraging the Rise of Drones, AI, and IoT, the agricultural sector is finally equipped to handle the volatility of the 21st century. These technologies offer a rare “win-win”: they increase the profitability of the farmer while drastically reducing the environmental footprint of food production. As these tools become more accessible and affordable, the vision of a sustainable, data-driven global food system moves from a research paper concept to a field-level reality.

References

- Food and Agriculture Organization of the United Nations. (2019). Digital technologies in agriculture and rural areas: Status report. FAO.
- Gebbers, R. and Adamchuk, V. I. (2010). Precision agriculture and food security. *Science*, 327(5967): 828-831.
- Kamilaris, A. and Prenafeta-Boldú, F. X. (2018). Deep learning in agriculture: A survey. *Computers and Electronics in Agriculture*, 147: 70-90.
- Liakos, K. G., Busato, P., Moshou, D., Pearson, S. and Bochtis, D. (2018). Machine learning in agriculture: A review. *Sensors*, 18(8): 2674.
- Wolfert, S., Ge, L., Verdouw, C. and Bogaardt, M. J. (2017). Big data in smart farming: A review. *Agricultural Systems*, 153: 69-80.
- Zhang, C. and Kovacs, J. M. (2012). The application of small unmanned aerial systems for precision agriculture: A review. *Precision Agriculture*, 13(6): 693-712.

DNA Sequencing: Advanced Mechanism

Mouli Paul, Obaidulla Khan and Vishal Singh

Introduction

DNA is the blueprint of life consisting of chemical building blocks called nucleotides. These building blocks are made of three parts: phosphate, sugar group, and one of the four types of nitrogen bases viz Adenine (A), Thymine (T), Guanine (G), or Cytosine (C). To form a strand of DNA, nucleotides are linked into chains, with the phosphate and sugar groups alternately (Studholme *et al.*, 2011). The order or sequence of these bases determines what biological instructions are contained in a strand of DNA. For example, the sequence ATCGTT might instruct for blue eyes, while ATCGCT for brown. Each DNA sequence that contains instructions to make a protein is known as gene. The size of a gene may vary greatly, ranging from about 1,000 bases to 2300 kilo bases in humans. DNA has double helical structure in which two strands run in opposite directions (Lasken and McLean, 2014). Each “rung” of the ladder is made up of two nitrogen bases; paired together by hydrogen bonds, because of the highly specific nature of this type of chemical pairing, base A always pairs with base T, and likewise C with G. Therefore, if the sequence of the bases on one strand

of a DNA double helix is known, it is simple to figure out the sequence of bases on the other strand. The entire sequencing of chromosomes has resulted in the most important genetic advances of the 1990s. The initial eukaryotic chromosome Chromosome III of *Saccharomyces cerevisiae* was fully sequenced and published in 1992. Following this, the bacterium *Haemophilus influenzae* had the first entire genome sequence for a free-living organism in 1995, and the first complete genome sequence of a eukaryotic organism, *S. cerevisiae*, followed in 1996. The full genome sequences of significant model species, including the fruit fly *Drosophila*, the nematode *Coenorhabditis elegans*, the plant *Arabidopsis*, and *Escherichia coli*, were later made public. Determining the DNA sequence of the entire genome or of its several transcripts is the primary goal of the majority of genome projects. As a result, all or most of the genes are identified, and different structural aspects of the genome are described. DNA sequencing is primarily utilized in many molecular biology labs to characterize recently cloned cDNAs, verify the identity of a clone or mutation, assess the fidelity of a newly generated mutation and find poly-

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morphism using PCR products and screening tools. These days, many organisms' entire genome sequencing data are available for genetic research thanks to the development of automated DNA sequencing and Next Generation Sequencing (NGS) (Deamer and Akeson, 2000).

Various Method of DNA Sequencing

Maxam-Gilbert Method: Piperidine and two substances that specifically target purines and pyrimidines are used in a two-step catalytic procedure that Allan Maxam and Walter Gilbert invented to sequence single-stranded DNA. The base is displaced when purines react with dimethyl sulfate and pyrimidines react with hydrazine in a way that breaks the glycoside bond that holds the ribose sugar to the base. When the base has been moved, piperidine catalyzes the breaking of phosphodiester linkages. Furthermore, whereas dimethyl sulfate and piperidine in formic acid cleave both guanine and adenine nucleotides, they only selectively cleave guanine nucleotides when used alone.

Sanger Method: An alternate technique was created by Frederick Sanger, who chose to use a third form of the ribose sugar in place of chemical cleavage reactions (Sanger *et al.*, 1977). In contrast to deoxyribose, which only has one hydroxyl group on the 3rd carbon, ribose has a hydroxyl group on both the 2nd and 3rd carbons. Dideoxyribose is a third type of ribose in which neither the 2nd nor the 3rd carbons have a hydroxyl group. Every time a polynucleotide incorporates a dideoxynucleotide, the chain terminates or stops irreversibly.

Automated DNA Sequencing Methods: The principle of automated DNA sequencing is same as Sanger's method but the detection is different. In this automated method, the primer or the ddNTPs are labeled by incorporation of a fluorescent dye. Thus, rather than running the gel for a particular time and reading the results, the machine uses a laser to read the fluorescence of the dye as the bands pass a fixed point. Labeling of the ddNTPs is much more advantageous than the primer labeling because four ddNTPs each labeled with different dyes leads the sequencing reaction to run in a single tube and separated in a single lane, thus increasing the capacity of the machine. Automated DNA sequencers can sequence up to 384 DNA samples in a single batch and run up to 24 runs per day. DNA sequencers carry out capillary electrophoresis for size separation, detection and recording of dye fluorescence, and data output as fluorescent peak trace chromatograms. Four-color fluorescent dyes have replaced the radioactive label. Attachment of these dyes to the ddNTPs results in a fluorescent tag directly marking just the terminated DNA molecule, and consequently a single sequencing reaction spiked with all four ddNTPs is sufficient to sequence any template. With the release of Applied Biosystem's ABI Prism in 1999, capillary electrophoresis replaced slab gel electrophoresis 3,700 sequencers that are automated. By eliminating the time-consuming and frequently annoying phase of gel pouring, these sequencers provide incredibly high quality, lengthy readings and introduce a new

level of automation by loading the capillaries from 96-well plates by robot rather than by hand. Each machine can process roughly 0.5 Mb of sequence, or six 96-well plates each day.

Whole Genome Shotgun Sequencing

The alternative to the clone-by-clone approach is the ‘bottom-up’ whole genome shotgun (WGS) sequencing. It was developed by Fred Sanger in 1982. First, DNA is broken into fragments followed by sequencing at random and assembling together the overlaps. Advantage of the whole genome shotgun is that it requires no prior mapping. Its disadvantage is that large genomes need computing power and sophisticated software to reassemble the genome from its fragments. Unlike the clone-by-clone approach, assemblies cannot be produced until the end of the project. Whole genome shotgun for large genomes is especially valuable if there is an existing ‘scaffold’ of organized sequences, localized to the genome, derived from other projects. Uncertainties are resolved more easily when the entire genome shotgun data is placed on the “scaffold” sequence. The majority of bacterial genomes are currently shotgunned, and many other genome projects use it as a “top-up” of sequence data.

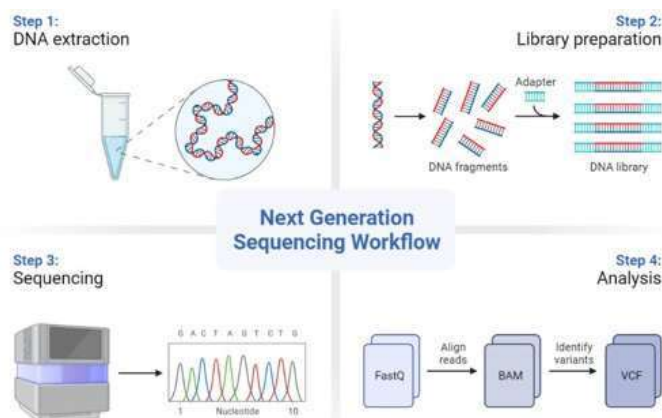
Recent Advances in DNA Sequencing

Over the past five years, numerous firms, service agencies, and methodologies have developed scientifically more sophisticated methods and economically viable services, including Microchip, Roche Applied Science, and 454 Life Sciences.

Agencourt Bioscience, Biotechnologies and numerous others. Ten years after the Human Genome Project was finished, a spectacular increase in sequencing technology has made it possible to ask and answer a large number of questions about the genome with previously unheard-of speed and detail. Although the cost of DNA sequencing has decreased to almost nothing for some applications due to advancements in sequencing technology, a wider variety of scientific experiments can now be conducted. However, this has also made it possible for DNA sequencing to be used in absurd ways and increased the strain on storage resources (Pettersson *et al.*, 2009).

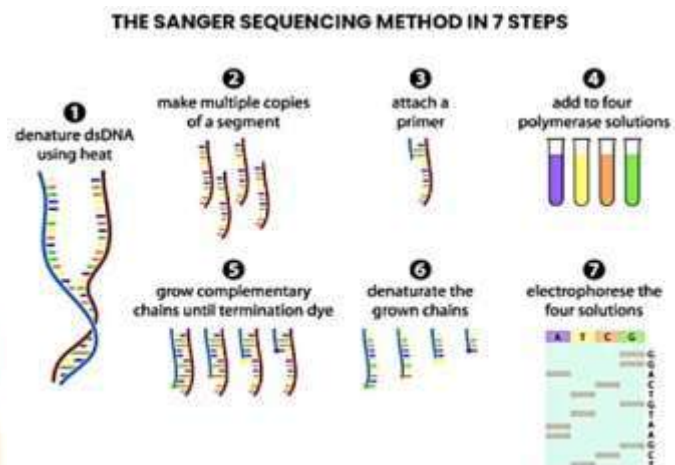
Next-Generation DNA Sequencing: Next-generation DNA sequencing, a new generation of non-Sanger sequencing technologies, has the potential to significantly speed up biological and biomedical research by making DNA sequencing possible at previously unheard-of speeds. In contrast to requiring substantial production-scale efforts, comprehensive analysis of genomes, transcriptomes, and interactomes has several benefits, including being broad, routine, and affordable (Xiaoguang *et al.*, 2010). First, a library of DNA templates is created. DNA library fragments are made from either pair-end fragments with a controlled distance distribution or randomly sheared genomic DNA (10 s to 100 s bp in size). DNA clusters or amplified beads form an array of DNA clusters on a slide, which then undergo cyclic manipulation through enzyme such as polymerase or ligase. Optical events

generated from the cyclic chain extension process are monitored by microscopic detection system, and images recorded through CCD camera. Sequential analysis of array image yields DNA fragment sequences, which are assembled into larger sequence contigs by computer algorithm.



Sanger sequencing: The Sanger technique is a mixed-mode approach that uses natural 2-deoxy nucleotides (dNTPs) to synthesize a complementary DNA template and DNA polymerase to terminate synthesis using 2,3-deoxynucleotides (ddNTPs). Competition between the synthesis and termination processes, when properly balanced, produces a collection of nested fragments that differ in nucleoside monophosphate units. The frequency of chain termination is determined by the ratio of dNTP/ddNTP in this sequencing procedure, which also determines the distribution of lengths of softerminated chains. High-resolution gel electrophoresis is then used to separate the fragments according to size, and the DNA sequence is subsequently revealed through analysis. Both the primer and the ending ddNTP are labeled with a particular fluorescent dye for automated Sanger sequencing (for example, ddATP is labeled with the

green dye). As the dye-labeled fragment. Fluorophores are excited by the laser in the DNA sequencer as they travel through the detection zone, resulting in fluorescence emissions of various hues. The DNA sequence is revealed by the order of the fluorescent fragments, and the color determination is the fundamental way for assigning a base call.

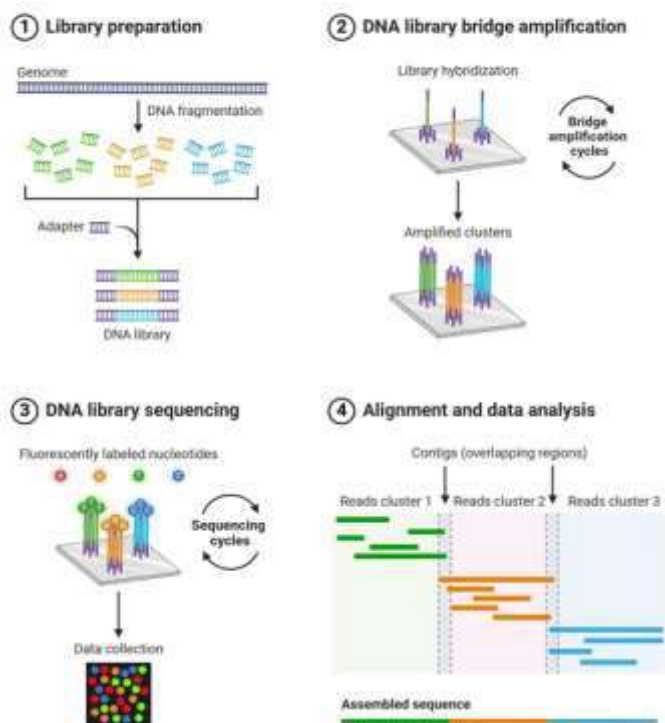


Illumina Genome Analyzer: The amplification of single-stranded library fragments is carried out through a process called “bridge amplification.” In Illumina/ Solexa sequencing [50 million clusters/ flow cells, each with 1,000 copies of the same template, 1 billion bases per run, and 1 % of the cost of capillary-based method makes it cost effective, highly accurate, straightforward sample preparation, well established open source software community and less time consuming method. Illumina Hi-seq produces approximately 1.6 billion short reads (18-150 bp) per flow cell, whereas Illumina Mi-seq produces 7.5 Gbase/run producing 29250 bp fragments.

Nanopore DNA Sequencing: Oxford Nanopore Technologies has created yet another single molecule TGS that incorporates nucleotides through the

use of nanopore technology. A signal is recognized when the DNA sequence travels through a nanopore with an internal diameter of 1 nm, changing the pore's electrical conductance. Protein nanopores embedded in the polymer membrane are used in this method (Hart *et al.*, 2010). The sequencing does not need any intervening PCR amplification or a chemical labeling step. In addition there is no need for sample preparation as cell lysate can be directly sequenced.

Illumina Sequencing Steps



Roche 454 Genome Sequencer: Emulsion PCR is utilized by the 454 Sequencer to produce the amplicons needed for the sequencing process. The single-stranded template DNA library and the ingredients required for the PCR reaction are combined with tiny paramagnetic beads coated with DNA primers. To guarantee that the majority of

beads carry only one ssDNA molecule, a proportionate amount of beads and library fragments are combined. Each water component of the emulsion created by mixing the aqueous solution with oil acts as a separate micro-reactor for the PCR chemistry that follows. Each bead has thousands of copies of the same sequence of DNA deposited on it following several rounds of thermocycling.

Pyrosequencing: It is a DNA sequencing technique that uses the “sequencing by synthesis” approach to ascertain the nucleotide order in DNA. It is different from Sanger sequencing in that it uses luciferase and ATP sulfurylase to initiate a series of biological reactions that culminate in the emission of a burst of biochemiluminescent light. Apyrase is a nucleotide-degrading enzyme that breaks down ATP and unincorporated nucleotides. Another nucleotide is inserted following degradation. Each of the four dNTPs is introduced into the flow cell one after the other to accomplish sequencing. The identification of the complementary base on the template DNA in that well is shown by the presence or absence of light burst in each picotiter well, which signifies the integration of the corresponding nucleotide.

Conclusion

The process of determining a DNA fragment's base sequence is known as DNA sequencing. The most widely used technique is the Sanger method of DNA sequencing, which repeatedly creates a new DNA strand using a DNA segment as a template utilizing DNA polymerase I and a PCR reaction. When an adideoxynucleotide is added in

place of a regular nucleotide, strand synthesis comes to an end. An automated sequencer or a manual method can be used for Sanger sequencing. Many novel DNA sequencing techniques and sequencers, such as the Illumina Genome Analyzer, pyrosequencing, SOLiD Sequencing Chemistry, 454 Genome Sequencer, etc., have recently been created that are completely automated and need less time and money. DNA/genome sequencing has been utilized in forensics, medicine, and agriculture. It can be used to identify microbes that cause diseases, detect genes linked to acquired or hereditary diseases, boost production, and make plants more resistant to pests, among other uses.

References

- Studholme, D. J., Glover, R. H. and Boonham, N. (2011). Application of high-throughput DNA sequencing in phytopathology. *Annual Review of Phytopathology*, 49(1): 87-105.
- Lasken, R. S. and McLean, J. S. (2014). Recent advances in genomic DNA sequencing of microbial species from single cells. *Nature Reviews Genetics*, 15(9): 577-584.
- Deamer, D. W. and Akeson, M. (2000). Nanopores and nucleic acids: prospects for ultrarapid sequencing. *Trends in Biotechnology*, 18(4): 147-151.
- Xiaoguang, Z., Lufeng, R., Yuntao, L., Meng, Z., Yude, Y. and Jun, Y. (2010). The next-generation sequencing technology: a technology review and future perspective. *Science China Life Sciences*, 53(1): 44-57.
- Sanger, F., Nicklen, S. and Coulson, A. R. (1977). DNA sequencing with chain-terminating inhibitors. *Proceedings of the National Academy of Sciences*, 74(12): 5463-5467.
- Pettersson, E., Lundeberg, J. and Ahmadian, A. (2009). Generations of sequencing technologies. *Genomics*, 93(2): 105-111.
- Hart, C., Lipson, D., Ozsolak, F., Raz, T., Steinmann, K., Thompson, J. and Milos, P. M. (2010). Single-molecule sequencing: sequence methods to enable accurate quantitation. In *Methods in Enzymology* (Vol. 472, pp. 407-430). Academic Press.

Millet's Bioethanol: Fueling a Greener Tomorrow

Nataraja K. D. and Sumanlata Rawat

Introduction

Natural resource shortage has become a significant problem in several regions around the world. Worldwide resource scarcity has resulted from rapid population growth and rising industrialization, as well as from emissions of greenhouse gases causing climate change and global warming. The impact of the global climate crisis is a series of progressive repercussions that influence people, animals, and a variety of plants by altering the fundamentals of life, including food security, the destruction along dispersion of habitats. Numerous clean air policies encourage renewable energy resources and demonstrate great efficiency in significantly minimizing the adverse impacts of climate change. Fossil fuels are among the limited resources that are rapidly depleting (Wang and Azam, 2024). "Fossil fuels" are nonrenewable carbon-derived energy sources, such as natural gas, petroleum, and solid fuels, which are made up of the remains of plants and animals that lived several million years ago and have experienced both physical and chemical change in the earth's crust, or lithosphere (Itskos *et al.*, 2016). An estimated 80.3% of the world's primary energy consumption comes from fossil fuels, with 57.7% coming from the trans-

portation sector. Fossil fuels, including petroleum are detrimental to the atmosphere and have a major influence in climate change worldwide. One of the main causes of concern for global climate change is CO₂ emissions from fossil fuels. CO₂ emissions increased by about 60% from 22.7 billion tons in 1990 to an anticipated 36.44 billion tons in 2019. The burning of fossil fuels at the current rate is likely to create an environmental crisis globally through the generation of carbon dioxide (CO₂), methane (CH₄), and a significant quantity of nitrous oxides. Most of these harmful gases are formed due to incomplete combustion of fossil fuels. As a result of this, there is a growing international quest for an alternative energy source. Ethanol produced from biomass through fermentation contains 35% O₂ that may result in a more complete combustion of fuel and thus reduces tailpipe emissions (Chandel *et al.*, 2007). Moreover, biomass energy can play an important role in reducing greenhouse gases emissions. Ethanol production process only uses energy from renewable energy sources. Hence, no net carbondioxide is added to the atmosphere, making ethanol an environmentally beneficial energy source. In addition to their nutritional importance, millets are becoming more widely acknowledged for their

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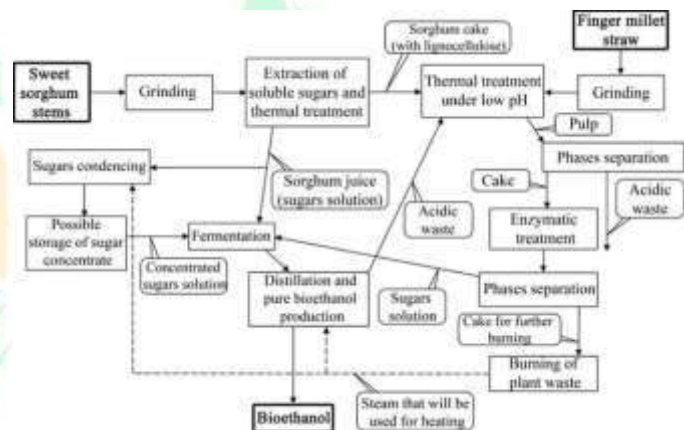
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potential in producing bioenergy, especially ethanol, which promotes a dual-purpose agricultural paradigm. India, a country facing environmental issues and a growing population, must strike a balance between water sustainability and energy security. The nexus between water and energy is particularly pertinent in India, where agriculture, a water-intensive sector, is vital to the nation's economy. As climate change exacerbates water scarcity issues, the exploration of alternative biofuel sources becomes imperative to alleviate the environmental burden associated with conventional fuels.

Millet as an Emerging Bioenergy Resource Ensuring Food Security

Millets are increasingly recognized as promising feedstocks for bioethanol production due to their high biomass yield, adaptability to water-scarce conditions, and compatible fermentation properties. Multiple millet types including pearl millet, finger millet, sorghum, proso, foxtail, barnyard, and little millet have demonstrated viable ethanol yields, often comparing favorably with traditional bioethanol crops like corn and sorghum when optimized processes are employed. India is the world's largest producer of millets, accounting for around 41% of total global output, with strong government support for expanding ethanol blending and production. Recent policies encourage both food and non-food applications of millets, including bioethanol, which aligns well with India's focus on sustainable crop use and renewable energy targets.

Integrating millet as a bioethanol resource is receiving more attention worldwide, particularly in areas where water shortage restricts the options for other cereals. India is the world's top producer of millet crops, followed by China and Niger. Due to the lack of an appropriate method or application for their processing, a significant amount of millet chaff is created as residues during its production and is mostly burned or dumped. Due to its ability to withstand heat, resistance to drought, and lower water requirements than corn, pearl millet may generate huge amounts of fodder (Wu *et al.*, 2006).



Bioethanol Production Process

The production of bioethanol from millets involves several steps, which are described below:

Milling: Millets are cleaned and milled to produce flour, which is then mixed with water to create a mash. The milling process involves breaking down the millet grains into smaller particles, increasing the surface area for enzymatic hydrolysis.

Saccharification: Enzymes, such as alpha-amylase and glucoamylase, are added to the mash to break down starches into fermentable sugars. This process is typically carried out at a temperature range of 50-

60°C and pH 4.5-5.5. This reaction usually takes 30-60 minutes time for completion of process.

Fermentation: Yeast, typically *Saccharomyces cerevisiae*, is added to the mash to ferment the sugars, producing ethanol. 0.5-1.5 kg per one ton of millet.

Distillation: The fermented mash is distilled to separate the ethanol from the stillage (wastewater). The distillation process involves heating the mash to produce a vapor, which is then condensed to produce a liquid containing 95% ethanol. Distillation temperature should be 78-80 °C.

Dehydration: The ethanol is further dehydrated using molecular sieves or other technologies to produce anhydrous bioethanol (99.5% ethanol). The bioethanol production process can be optimized to improve efficiency, reduce energy consumption, and minimize waste generation.

Major Millet Types and Ethanol Potential

Pearl Millet: Pearl millet biomass and grain have fermentation efficiencies similar to corn when using *Saccharomyces cerevisiae*, often reaching 90-95% conversion rates in controlled fermentations.

Proso Millet: Emphasis is placed on breeding “highly fermentable” lines to boost ethanol yield, demonstrating notable potential alongside ongoing genetic improvement efforts. Sweet sorghum varieties are prominent due to their high juice sugar content, and both grain and stem are suitable for ethanol extraction (Shinde *et al*, 2024).

Foxtail, Barnyard and Little Millet: Husk and agricultural waste from these minor millets can be

efficiently converted into ethanol, with autoclaved alkaline pre-treatment showing superior results for barnyard millet husks.

Finger Millet: Both straw and grain are viable; straw offers up to 3800 L ha⁻¹ ethanol yields, but pre-treatment complexities restrict economic scalability. Advanced pretreatment with green solvents (e.g., ionic liquids) enhances saccharification and ethanol yield.

The Conflict of Biofuel and Food Security

Competition for Cultivable Land: The persistent global food crisis, driven by population growth, underscores the tension between food and fuel production. Bioethanol production requires large areas of arable land, and expanding biofuel crop cultivation often encroaches on land traditionally used for food crops. As farmers shift from food production to biomass cultivation, it raises serious concerns regarding food availability and security.

Resource Competition: Biofuel crops demand substantial amounts of water and nutrients, putting additional strain on regions already facing resource scarcity. This competition for limited natural resources can contribute to environmental degradation and undermine long-term sustainability goals.

Sustainable Biofuel Production: The focus must shift toward sustainable biofuel production that safeguards cultivable land and food security. Developing non-food-based feedstocks, such as jatropha, offers a promising approach since these crops can thrive on barren or degraded lands, turning them into productive areas. In contrast, reliance on

food crops like sugarcane and corn for ethanol production should be minimized to prevent land-use conflicts. Utilizing agricultural residues such as crop stubble, rice husks, wheat straw, and sugarcane bagasse for bioethanol production provides a viable alternative. Although challenges remain in ensuring the sustainability of such processes, these innovations can significantly reduce pressure on arable land and avoid competition with food production.

Comparison of Millet Cultivation with Other Bioenergy Crops:

Compared to conventional bioenergy crops like sugarcane and maize, millets have a number of agronomic and ecological advantages that make them a great substitute feedstock for the production of sustainable bioethanol. Although the cultivation of bioenergy crops necessitates a sufficient supply of water, water scarcity frequently exacerbates the conflict between food and fuel, and millets' naturally high WUE makes them especially suitable for marginal and semi-arid regions. Recent research suggests that millets are a promising feedstock for both biofuel production and effective management of water resources. Furthermore, unlike the soil deterioration frequently linked to intensive sugarcane and maize growing, millet cultivation promotes soil health and biodiversity. In addition to lowering greenhouse gas (GHG) emissions, millet-based bioenergy systems enhance overall environmental sustainability through phytoremediation, carbon sequestration, and soil quality enhancement.

Conclusion

The increasing global energy consumption and carbon dioxide emissions from fossil fuel burning pose a significant issue in the modern era. Alternative energy sources are now necessary due to depletion of fuels derived from petroleum sources and their associated environmental impact. This is a very promising alternative crop that can be used not only for the production of high nutritionally valuable food, but also as an efficient source of biomass for bioethanol production. This millet is very attractive for utilization as a bioenergy crop due to several advantages that, when realized in the future, can further improve this crop.

References

- Chandel, A. K., Chan, E. S., Rudravaram, R., Narasu, M. L., Rao, L. V. and Ravindra, P. (2007). Economics and environmental impact of bioethanol production technologies: an appraisal. *Biotechnology and Molecular Biology Reviews*, 2(1): 14-32.
- Itskos, G., Nikolopoulos, N., Kourkoumpas, D. S., Koutsianos, A., Violidakis, I., Drosatos, P. and Grammelis, P. (2016). Energy and the Environment. In *Environment and Development* (pp. 363-452). Elsevier.
- Wu, X., Wang, D., Bean, S. R. and Wilson, J. P. (2006). Ethanol production from pearl millet by using *Saccharomyces cerevisiae*. In 2006 ASAE Annual Meeting (p. 1). *American Society of Agricultural and Biological Engineers*.

- Shinde, D., Karanje, S. V., Godase, S. S., Jagdale, Y. L. and Jadhav, M. A. (2024). Possibilities of Bioethanol Production from Millet Crops. *Research Advances and Challenges in Agricultural Sciences*, 2: 57-71.
- Wang, J. and Azam, W. (2024). Natural resource scarcity, fossil fuel energy consumption, and total greenhouse gas emissions in top emitting countries. *Geoscience Frontiers*, 15(2): 101757.



Modern Drying, Grading, Packaging, and Processing Approaches in Horticulture

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Introduction

The global population is rapidly increasing and is projected to continue doing so for the rest of this century. Research suggests an 80 per cent likelihood that by 2100, the world's population will rise from 7.2 billion to between 9.6 and 12.3 billion (Gerland *et al.*, 2014). With this growth comes a significant surge in food demand, particularly as the middle class in developing countries becomes wealthier. It's estimated that global food demand could increase by 50 per-cent to 70 per-cent by the middle of this century (Godfray, 2010). The horticultural sector holds significant potential for the development of wastelands through well-planned system. Compared to traditional food crops, horticultural crops require comparatively less water, provide higher employment opportunities and are more environment-friendly. From the perspective of nutritional security, fruits and vegetables be prominent due to their potential for value addition, which not only enhances their market value but also contributes substantially to foreign exchange earnings. The horticultural crops are thus not only agricultural products but pivotal commodities in commerce, having gained substantial market potential globally. In the context of the Indian agricultural economy, horticultural crops have a significant role,

contributing approximately 30% to the GDP from just 11.73% of the total arable land area. The high rate of post-harvest losses in India can be attributed to various factors, including inadequate infrastructure, inefficient supply chains and insufficient processing facilities. These losses not only reduce the net availability of produce but also represent a significant economic drain, estimated at Rs. 23,000 crores annually. The Swaminathan Committee reported that post-harvest handling accounts for 20-30% of losses at different stages, including storage, grading, packing, transport and marketing. Globally, it is estimated that 20 - 40% of horticultural produce is lost post-harvest, with even higher figures reported in tropical and subtropical countries where temperature and humidity accelerate spoilage (Ranjan and Sahni, 2023). The losses that happen after harvesting are known as postharvest losses. It is defined as the losses resulting from total qualitative loss, total quantitative loss, and total food waste (by consumers) from the time of harvest to the point of consumption. Five processes can lead to postharvest losses in horticultural commodities: production/harvest, handling and storage following harvest, processing, distribution and consumption. Inadequate packaging and rough handling further aggravate bruising, cracking, and shrinkage, especially in delic-

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ate fruits such as mangoes, bananas, and grapes. Vegetables like tomatoes, onions, and cabbages are prone to microbial decay, wilting, or sprouting under poor storage conditions. Ornamental crops such as cut flowers face severe post-harvest losses due to rapid wilting, petal drop, and fungal infections, often exceeding 30%.

Drying Technologies in Horticulture

One of the earliest and best post-harvest preservation techniques for horticultural products is drying. It prolongs shelf life, inhibits enzymatic processes, and limits microbial development while lowering storage and transportation expenses by lowering moisture content. In horticulture, drying is a common method for preserving the flavor, color, and nutritional value of fruits, vegetables, spices, and herbs.

Improved Solar Drying: To overcome the limitations of open sun drying, solar dryers have been developed. Cabinet dryers, tunnel dryers, and hybrid solar dryers combine solar energy with auxiliary heating or fans to improve efficiency. These systems provide more uniform drying, reduce contamination risks, and enhance product quality. They are particularly effective for small-scale farmers and cooperatives dealing with spices, herbs, and fruits (Udomkun *et al.*, 2020).

Hot Air and Mechanical Drying: Hot air dryers achieve faster and more consistent drying by using regulated airflow and temperature. Large-scale operations involving fruits like apples, bananas, and grapes as well as vegetables like onions and tomatoes

frequently use these dryers. Despite requiring more energy than solar systems, they provide consistent quality and short drying times (Gidado *et al.*, 2024).

Osmotic and Combined Drying: In osmotic drying, produce is immersed in concentrated sugar or salt solutions before conventional drying, which improves texture and flavor. Combined drying techniques, such as solar drying followed by hot air or microwave drying, optimize energy use and product quality.

Grading and Sorting in Horticulture

The marketability and value of horticultural crops are determined by two essential post-harvest processes: grading and sorting. Produce is categorized according to factors like size, weight, color, shape, and lack of flaws. In both domestic and international markets, proper grading guarantees consistency, boosts consumer confidence, lowers rejection rates, and enables better pricing (Yogita *et al.*, 2025). Mechanical, electronic, and digital technologies that provide speed, consistency, and accuracy are used in modern grading. Produce is categorized using roller graders, conveyor systems, and color sorters using optical sensors, weight, or size. High-value crops like apples, citrus fruits, and tomatoes can be precisely sorted thanks to sophisticated systems that use computer vision and artificial intelligence (AI) to identify internal and external flaws. These systems exceed export-grade standards, boost efficiency, and lessen reliance on labor, but they also need a substantial investment and technical know-how. In addition to lowering post-

harvest losses, grading and sorting increase farmers' and traders' profits. The use of automated and AI-driven grading systems is growing, especially in export-oriented horticulture sectors, even though manual grading is still crucial for small-scale operations.

Packaging Innovation

For horticultural produce, packaging is the first line of defense, shielding it from physiological deterioration, microbiological contamination, and mechanical damage during storage and transit. Packaging affects branding, consumer appeal, and adherence to food safety regulations in addition to preservation. Fresh and processed horticulture products' shelf life, safety, and economic worth are all greatly impacted by the material and form of their packaging. Horticultural product is typically packed in cardboard boxes, jute sacks, wooden crates, or bamboo baskets. Despite being inexpensive, these materials frequently offer little protection and may result in water loss, bruising, or compression during long-distance transportation. For instance, fruits like bananas and mangoes that are shipped in gunny bags frequently have uneven ripening and bruises. Modified Atmosphere Packaging (MAP) alters the composition of gases inside the package, typically by reducing oxygen and increasing carbon dioxide to slow respiration and delay ripening. This method extends the shelf life of fresh-cut fruits, leafy vegetables, and minimally processed products. Controlled Atmosphere Packaging (CAP), though more expensive, provides stricter regulation of gas

composition and temperature, suitable for export commodities such as apples, kiwifruits, and citrus (Nofiyanti *et al.*, 2025). Growing environmental concerns have spurred the development of biodegradable and edible packaging films made from starch, cellulose, or protein-based polymers. These films can be incorporated with natural antimicrobials such as essential oils, plant extracts, or probiotics, offering active protection against spoilage. Such eco-friendly packaging aligns with global sustainability goals and consumer preferences for green alternatives.



The future of post-harvest management and value addition

The future of post-harvest management and value addition in vegetables looks potential for enhancing food security, economic growth and agricultural sustainability. Processing techniques such as freezing, drying and fermentation can transform perishable vegetables into long-lasting products. Investment in research and development, improved infrastructure and innovative processing

Table 1: Comparison of conventional and modern packaging practices

Features	Conventional (Basket, Jute and wooden crates)	Modern Packaging (Plastic crates, MAP, Smart)
Cost	Low, locally available	Higher initial cost, but reusable or export compliant
Protection	Limited cushioning, high mechanical damage	Strong protection, cushioning, stackable
Shelf life extension	Minimal	Significant, especially with MAP/CAP
Sustainability	Biodegradable but often non-standardized	Options for biodegradable films and reusable plastics
Market acceptance	Local/regional markets	National and international markets
Value addition	Limited	High, supports branding, labeling, and consumer appeal
Innovation Potential	Low	High (smart sensors, traceability, antimicrobial coatings)

methods are key to unlocking the full potential of value addition in vegetable crops. These advancements will contribute to economic development, self-reliance and the growing demand for nutritious and high-quality produce.

Conclusion

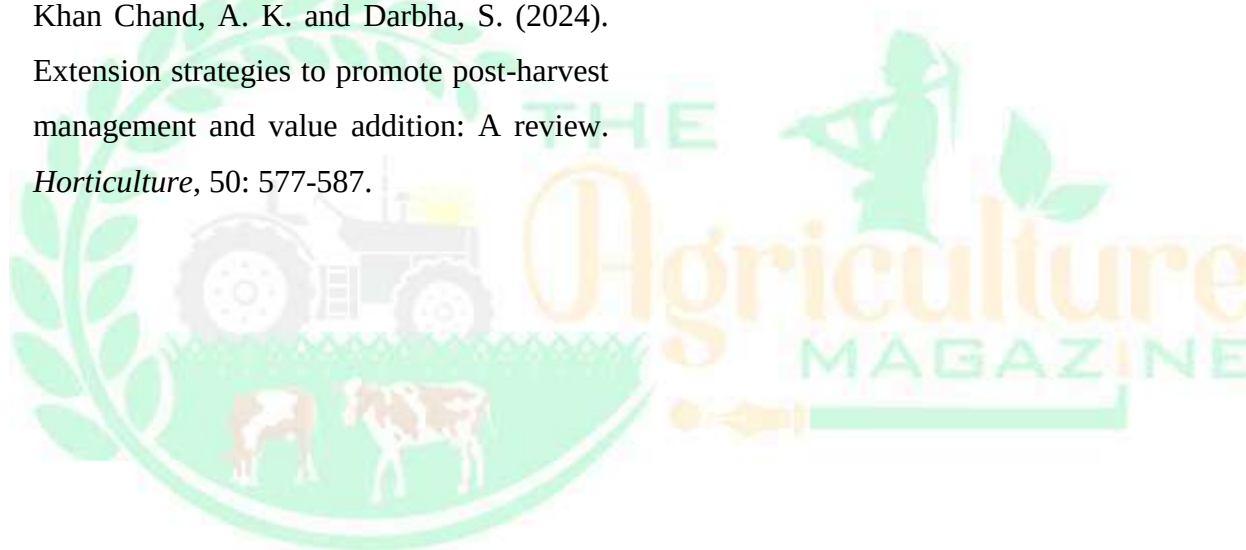
The current scenario underscores significant challenges in post-harvest management and the underutilization of value-addition techniques. However, the potential for innovation and market diversification is vast. Effective post-harvest management and value addition can reduce food wastage, enhance the economic value of vegetables and create new market opportunities. Collaborative efforts in research, technology and policy support are essential to realizing these prospects. By harnessing these opportunities, the agricultural sector can achieve improved sustainability, economic viability for farmers and enriched consumer choices, ensuring a brighter future for vegetable crop management. Sustainability will also be a defining feature of future strategies. The shift toward biodegradable packaging, circular use of by-products, and climate-smart technologies can align horticultural value addition with environmental goals. Moreover, consumer demand for functional foods, nutraceuticals, and

minimally processed products presents new avenues for entrepreneurship and export diversification.

References

- Gerland, P., Raftery, A. E., Ševčíková, H., Li, N., Gu, D., Spoorenberg, T., ... and Wilmoth, J. (2014). World population stabilization unlikely this century. *Science*, 346(6206): 234-237.
- Gidado, M. J., Gunny, A. A. N., Gopinath, S. C., Ali, A., Wongs-Aree, C. and Salleh, N. H. M. (2024). Challenges of postharvest water loss in fruits: Mechanisms, influencing factors, and effective control strategies-A comprehensive review. *Journal of Agriculture and Food Research*, 17: 101249.
- Godfray, H. C. J., Beddington, J. R., Crute, I. R., Haddad, L., Lawrence, D., Muir, J. F., ... and Toulmin, C. (2010). Food security: the challenge of feeding 9 billion people. *Science*, 327(5967): 812-818.
- Udomkun, P., Romuli, S., Schock, S., Mahayothee, B., Sartas, M., Wossen, T., ... and Müller, J. (2020). Review of solar dryers for agricultural products in Asia and Africa: An innovation landscape approach. *Journal of Environmental Management*, 268: 110730.

- Nofiyanti, S. H., Ahmad, U., Arista, Y. L., Hutabarat, M. A. and Rizqi, M. (2025). Advancing Modified Atmosphere Packaging for Horticultural Products: A Systematic Review and Bibliometric Analysis. *International Journal of Current Microbiology and Applied Sciences*, 14(02): 1-6.
- Ranjan, J. and Sahni, R. (2023). Post harvest losses of fruits and vegetables in India. *Ropan*, 9: 41-43.
- Yogita, R. J., Prajapati, C. S., Roy, S., Abrol, P., Khan Chand, A. K. and Darbha, S. (2024). Extension strategies to promote post-harvest management and value addition: A review. *Horticulture*, 50: 577-587.



Circular Horizons: Rethinking Waste Management for a Sustainable Future

Pooja Krishna J., Feba Varghese and Pungavi R.

Introduction

The growing feeling and awareness that the environment and society are interrelated entities that need to be examined and handled appropriately gave rise to the concept of sustainability. There are various interpretations of the sustainability concept, depending on the prioritization of the various academic disciplines. The ability to meet current social, economic, and environmental requirements without compromising the needs of future generations has previously been described as “sustainability”. Alternative interpretations of sustainability have focused on maintaining the world in a healthy, resilient, and adaptable state that promotes the flourishing of all species. It should be mentioned that the idea of sustainability is always changing. The study of how societal and environmental systems interact and impact environmental problems including water chemistry and climate modeling is known as sustainability science. Sustainability science is a rapidly expanding interdisciplinary discipline that uses engineering and policy approaches to manage human, ecological, and socioeconomic systems, according to Bettencourt and Kaur (2011). The discipline of sustainability science is expected to have a significant impact and has a global reach. Its growth has opened up new opportunities for

collaboration and cooperation in science. In recent years, sustainability science has gained momentum and is viewed as the most effective approach to addressing wicked problems. Wicked problems are unidentifiable problems that cannot be solved through straightforward solutions. Additionally, wicked problems are exacerbated by being manipulated by and collaborating with systems other than natural systems, such as the social and political domains. Solving such complicated problems requires an in-depth understanding of the stakeholders involved and an innovative design-thinking solution-based approach. Due to pollution, the worldwide production of biomass and waste residue from municipalities, the forestry and agriculture sectors, and other industries is a growing environmental concern (Nanda and Berruti, 2021). The use of biomass wastes is becoming more popular due to the expanding attempts to achieve sustainability. By maximizing their usage, reducing their production, and encouraging sustainability, managing organic wastes aims to lessen their detrimental effects on the environment. Gasification and anaerobic digestion (to produce gaseous fuels), pyrolysis and liquefaction (to produce liquid fuels), carbonization and torrefaction (to produce solid fuels), and composting (to produce biofertilizers) are some of the often

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employed waste management techniques.

Why Waste Management Matters?

Cities across the world generate billions of tonnes of solid waste every year, and this volume is rising with urbanization, changing lifestyles, and consumerism. When this waste is dumped in open sites or poorly managed landfills, it contaminates soil and water, attracts disease vectors, and releases methane, a potent greenhouse gas that accelerates climate change. In many developing countries, including India, a large share of municipal budgets is spent on waste collection and disposal, yet piles of mixed garbage still line streets and drains, revealing gaps in planning, infrastructure, and public participation.

Categories of Waste

Solid waste can be defined as non-liquid unwanted materials generated from human activities that is devoid of economic value after utilization. They cannot be reused directly for welfare of the society because of their adverse impacts on environment as well as human health. Solid waste (SW) in India might be recyclable, nonorganic, or organic. It comprises solid waste from industry, agriculture, municipalities, hospitals, radioactivity, and electronics that have varying degrees of impact on people and the environment. While agricultural solid wastes (ASW) contain metals and hazardous organic elements that have indirect effects on soil and groundwater quality, industrial solid wastes (ISW) primarily consist of hazardous materials. Organic and nonorganic, hazardous and nonhazard-

ous materials make up the majority of municipal solid wastes (MSW). The most contagious and dangerous kind of trash produced is biomedical solid waste (BMW), which can lead to a number of illnesses in both humans and animals.

Industrial Wastes: A significant quantity of hazardous waste is produced as a result of industrial operations, and in a nation like India that is rapidly industrializing, the contribution of industries to hazardous waste is at its highest. Depending on its nature and source, ISW might be classified as either hazardous or nonhazardous waste. Thermal power plants, integrated iron and steel mills, sugar, pulp and paper, and related industries are the main producers of hazardous ISW. Major hazardous substances such cyanides, complex aromatic compounds, heavy metals, insecticides, and goods with high chemical reactivity are produced by these industries. Because there are numerous industrial facilities in the nation, it is essential to manage these wastes in order to protect the natural resources.



Agricultural Wastes: Waste materials derived from different agricultural operations are defined as agri-

cultural wastes. Expansion of agricultural production has naturally resulted in increased quantities of livestock waste, agricultural crop residues, and agro industrial by-products. Agricultural waste otherwise called agro-waste includes livestock waste (manure, animal carcasses), food processing waste, crop residues (cornstalks, sugarcane bagasse, drops and culls from fruits and vegetables, pruning), green manures (sun hemp, cowpea, dhaincha, etc.), and hazardous and toxic agricultural waste (pesticides, insecticides, fertilizers, herbicides, etc.) (Pal *et al.*, 2014). Since major portion of the agricultural waste are organic in nature, it is used as fertilizer or for other soil enhancement activities. The residue materials are burned as a source of energy, so a very small portion of this waste is disposed in landfills. However, when excess agro-waste is produced in one place, there may not be enough land available to accept the agricultural waste, thereby causing problems of pollution and groundwater contamination.

Municipal Solid Wastes (MSW): Thousands of tonnes of MSW are produced every day in India as a result of people migrating from rural to urban areas due to the country's rapid industrialization and population growth. India's massive MSW generation is a result of both population growth and continuous industrialization of all solid garbage generated by municipalities. Nearly 79% of MSW is thought to be burned or dumped unscientifically in open landfills due to poor waste processing and the existence of a few sanitary landfills. GHG emissions from MSW

disposal were estimated to have been 11.67 million tonnes of CO₂ equivalent in 2015 (Kolsepatil *et al.*, 2019).

Radioactive Solid Waste: A byproduct of several nuclear technology processes is called radioactive waste. It encompasses any substance that is either naturally radioactive or has been tainted by radiation and is no longer useful. Nuclear medicine, nuclear research, nuclear power, nuclear reactors, manufacturing, construction, coal and rare earth mining, and nuclear weapons reprocessing are among the industries that produce radioactive waste. Along with other heavy metals like cerium and strontium, uranium and plutonium make up the majority of radioactive waste. Radiation from these heavy metals has detrimental effects on both the environment and human health.



E-Waste: The term “electronic waste” (also known as “e-waste”) describes electrical and electronic devices that have either outlived their usefulness to consumers or no longer fulfill their original purpose due to obsolescence, discarding, replacement, or breaking. It encompasses both “brown goods” like televisions, radios, computers, and cell phones as well as “white goods” like refrigerators, washing

machines, and microwaves. Along with potentially dangerous materials like chlorofluorocarbon and hydrochlorofluorocarbon (CFCs/HCFCs) gases, which have a significant potential to deplete the ozone layer, this trash contains metals including cadmium, lead, antimony, nickel, and mercury. India's information technology sector has grown at an unparalleled rate in recent years, and as a result of advancements in electronics technology, the amount of e-waste produced has skyrocketed.

What can Households and Communities do?

The most powerful change begins at the source: simple practices like separating wet (biodegradable) waste from dry (recyclable) and hazardous waste at home determine whether materials can be recovered or are condemned to dumps. Kitchen and garden waste, which make up a large share of household garbage, can be turned into compost through home or community systems, reducing landfill load and closing the nutrient loop for urban gardens and farms. Everyday choices carrying a cloth bag, refusing unnecessary single-use plastics, buying in bulk instead of heavily packaged items, and switching to durable, repairable products quietly but steadily shrink a household's waste footprint. Parents and schools can turn waste segregation, upcycling, and composting into hands-on projects for children, building environmental responsibility as a life skill rather than a one-time campaign.

Waste Minimization Initiatives

Developing and encouraging at-source reduction

programs: The promotion of different programs stating the importance and advantages of waste minimization at source in the community. For example, household/backyard composting programs can reduce the volume of food waste, domestic waste, leaves, and garden trimmings entering the city-level collection system.

Supermarkets and retail stores: These are the most effective partners for a waste minimization program. They provide the basis for consumer knowledge on how to avoid overpackaging and collect recyclable waste.

Awareness and education programs: Programs that address the importance of waste management should be implemented to increase public awareness and participation in at-source waste reduction programs. Campaigns relating to promotion of material substitution (e.g., promoting the use of rechargeable batteries instead of single-use batteries, repurchasing of products, etc.) should be organized.

Prohibition of product at community/city level: Replacing the use of a non-recyclable product with recyclable and reusable material, for example, banning the use of polythene bags.

Promoting product exchange and reuse programs : These help in diverting material from the waste stream before going to the landfill. It is the program that link sellers of used products with potential secondhand buyers.

Development of voluntary action: Business groups should be encouraged to reduce volumes of packaging. The business groups can ensure that the pack-

aging of the supplied product is taken back by the supplier and is reused.

The Road Ahead: From Linear to Circular

Conventional “take-make-dispose” strategies view nature as a bottomless container and an endless supply, but growing garbage mountains and climatic risks demonstrate that this assumption is no longer viable. A circular economy incorporates waste management with climate, health, and livelihood objectives, creates methods to recover materials at every level, and develops goods for durability, repairability and recyclability. Decentralized composting, biogas plants, material recovery facilities, and advanced recycling are examples of technologies that can only be successful when they are matched by social innovation, which includes knowledgeable citizens, responsive local governments, and inclusive policies that acknowledge and assist informal workers in the waste value chain.

Conclusion

One of the major environmental issues is trash management. The amount and quality of solid waste generation have significantly increased due to population growth, fast urbanization, a thriving economy, and rising living standards. Inadequate waste management poses a serious risk to human health because it alters the environment and pollutes the air, water, and soil. The characteristics of solid waste are significantly impacted by inappropriate bin collection, segregation, transfer and disposal methods, which also have detrimental indirect effects on the environment and the general public.

The depleting “produce-consume-dispose” economy must give way to a more regenerative and restorative “reduce-recover-reuse-recycle-redesign-remanufacture” circular economy.

References

- Bettencourt, L. M. and Kaur, J. (2011). Evolution and structure of sustainability science. *Proceedings of the National Academy of Sciences*, 108(49): 19540-19545.
- Nanda, S. and Berruti, F. (2021). Municipal solid waste management and landfilling technologies: a review. *Environmental Chemistry Letters*, 19(2): 1433-1456.
- Pal, M., Kumar, M., Gupta, G. R. and Dwivedi, K. N. (2014). Utilization of unused bio-waste for agricultural production-a review. *Plant Archives*, 14(1): 597-604.
- Kolsepatil, N., Anandhan, S., Sekhar, A. and Chaturvedula, S. (2019). Greenhouse gases emissions of India (subnational estimates): waste sector (2005-2015 series) (2019), Dated 25 Sept 2019. Retrieved from <http://www.ghgplatform-india.org/waste-sector>.

Beneficial Microbes for Agricultural and Dairy Industries

Raj Umakant Zadke, Kamble Prasad Pandhari and Tank Varsha Shyam

Introduction

Biotechnology is making the use of micro-organisms including fungi, bacteria, and viruses in fields of agriculture, food, and pharmaceutical products. Farmers and researchers are working to make the microbes as pests control agent that is destructive to their crops. Soil microbes, including bacteria and fungi, are essential for decomposing organic matter and recycling dead plant material. The agricultural productivity of soil can also be improved by microbes found in the soil. Today man is making use of naturally occurring microbes to produce the biological products that have ability to recycle the nutrients and are eco-friendly. The microbial world is the largest unexplored reservoir of biodiversity on earth (up to the last century, the nature and identity of only a tiny fraction (just <10%) of microscopic landscape is known. They make up the majority of life on Earth. Despite being the tiniest forms of life, microbes are considered to be essential to every spectrum of an earthly living organism's actions. As a result, microbial ecology research becomes a significant area of study in modern biology. The organisms that make up the enormous resources of microbial diversity activities include bacteria, fungus

algae, protozoa, actinomycetes and infectious agents including viruses (Andreote *et al.*, 2014). Through a variety of methods, microbial populations do interact and form associations in a variety of activities. It was also observed that few microbes live in the soil which helps the plant. It eats food from the plant but it fertilizes the land and snatching nitrogen from the air and add to soil which latter are used by plant. It was observed in shaftal plant. Where rhizoid live in root of the shaftal and add nitrogen to root of shaftal and make the soil fertile. Through this way the soil has been fertile which latter on provide nitrogen to other plants when we grown in that soil. There are some bacteria which spoil vegetable and fruits while it was also observed that in food industry the mold and yeast bacteria have a great role. There are virus which live on grasses plant which give protection from heat and droughtiness while sometime it destroy the plant leaves. In biotechnology and biomanufacturing, these tiny microbes and living cells are like miniature chemical factories that produce the vital products such as amino acids, enzymes, medicines, and food additives (Schmeisser *et al.*, 2007). Naturally, microorganisms are used to carry out fermentation processes and for thousands

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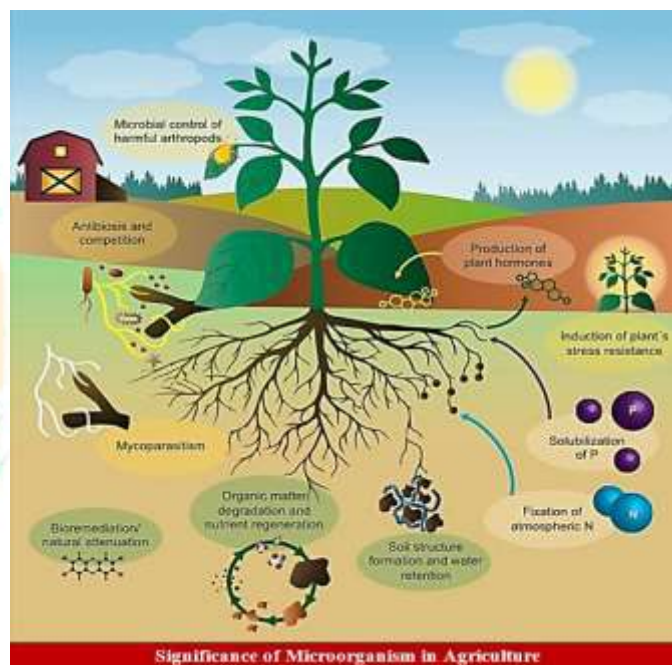
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of years man has been using yeasts, molds and bacteria to produce many of food products, that is, bread, vinegar, beer, wine, cheese, and yoghurt, as well as fermented fish, meat, and vegetables by making the use of microorganisms. According to FAO/WHO, probiotics are defined as living organisms that benefit consumer health when ingested in appropriate concentrations. Most of the probiotics used by the food industry are lactic acid bacteria (LAB), because of their essential role in nutrition and food processing. By making the use of microorganisms in large quantity, numbers of biological preparations have been prepared that have the great importance in field of medicine and pharmacy (Kapoor *et al.*, 2020).

Role of Microbes in Agricultural Industries

The food industry and global agriculture are constantly under pressure to supply adequate food for the world's population, which is expanding at an exponential rate. Fertilizers, biological control agents, and tillage techniques are the obvious solutions due to limited land resources. However, the use of chemical-based herbicides and fertilizers eventually harms the ecosystem and raises concerns about food safety (Taylor *et al.*, 2002). The use of different chemical rations and preservatives to increase food safety by extending its shelf life is also entirely safe to eat. Since microorganisms actively participate in many biological processes and maintain life on Earth, they can be extremely important in accomplishing these objectives. The microbes have the ability to improve soil health by

mineralizing nutrients and increasing soil fertility, biocontrol, and can also help in promoting plant growth without any negative impact on the environment. Improving food processing, storage, and preservation techniques is as important for food security as increasing agricultural productivity. Again, the microorganisms can be used to increase the shelf life of various food products as well as to convert food waste into an edible form using fermentation technology.



Microbes as Biofertilizers: The scarcity of nutrients is a significant issue for agricultural land production. Many techniques are used to improve soil fertility since plants need different nutrients in the right amounts for optimal growth. One such approach is integrated soil fertility management (ISFM), which uses biological fixation of atmospheric nitrogen, resource conservation and improving input competency to boost soil fertility. The use of fertilizers is a crucial stage in the management of nutrient content.

Chemical fertilizers can have detrimental consequences on human health and the soil environment when used to increase agricultural output. Because of their affordability and environmental benefits, living cell-based fertilizers, often known as “biofertilizers,” are the substitutes for chemical fertilizers used in sustainable agriculture (Mohammadi and Sohrabi 2012). In order to mineralize or fix the necessary elements and change them from an inaccessible form to an accessible form that can be utilized for plant growth, the living organisms that create the biofertilizers invade either the rhizosphere or the interior of the plant. The various groups of microorganisms used as biofertilizers include nitrogen fixers, phosphate solubilizers, and potassium solubilizers.

Rhizobium: Rhizobia are the soil habitat bacteria that have ability to clone in lines of roots of legume plants and can fix much of free nitrogen. In regard to the quantity of nitrogen they fix, they are the most efficient Biofertilizers.

Arbuscular mycorrhizal fungi: The intracellular obligate microbes are present in association with the root cortex of higher plants and absorb the essential elements including phosphorus, zinc, and sulfur from the soil. They can work as biofertilizer and are mostly from the genus *glomus*.

Azotobacter: Other than rhizobium bacteria, the azotobacter also has an ability to fix nitrogen. The several species of azotobacter are present in the soil and can act as biofertilizer.

Cyanobacteria: Cyanobacteria is a blue green algae

and found as free living or as symbiotic association with rice crop and can produce the fixed nitrogen at the rate of 20-30 kg nitrogen per hectare under ideal conditions and nowadays it is being used as biofertilizer.

Microbes as Biopesticides: A variety of bio-based compounds with various modes of action that combat invertebrate pests are referred to as biological pesticides, or biopesticides. Studies examining the pathogenic link between several bacterial species in the Bacillaceae family and invertebrates, particularly insects, have been conducted for a long time. The most researched and widely employed bacterium species, *Bacillus thuringiensis* (Bt), is a good representative of this class of entomopathogens. Numerous genera and species of invertebrate pathogenic fungus work against a wide range of targets and exhibit differing levels of specificity. Conidia or spores that have come into touch with the host cuticle typically germinate to begin the infection process. One of the most popular fungal bioinsecticides is *Beauveria bassiana*, which was the first instance of insect microbial control near the close of the 1800s. *B. bassiana* and *B. brongniartii* isolates from the same genus that exhibit different degrees of virulence against different targets are being employed as active ingredients in various formulations. Another widely used fungal species is *Metarhizium anisopliae*, which has a variety of strains that attack a variety of targets (Zimmermann, 2007). Numerous virulence factors and insecticidal toxins generated by strains of *M. anisopliae* have

been found. Other fungal species commercially exploited worldwide for pest management include *Verticillium lecanii*, *Lecanicillium* spp., *Hirsutella* spp., *Paecilomyces*, and *Isaria* spp., whose action is associated with the production of insecticidal metabolites. Several other entomopathogenic fungal species are associated with insects and play an important role in their natural control through the spread of their spores.

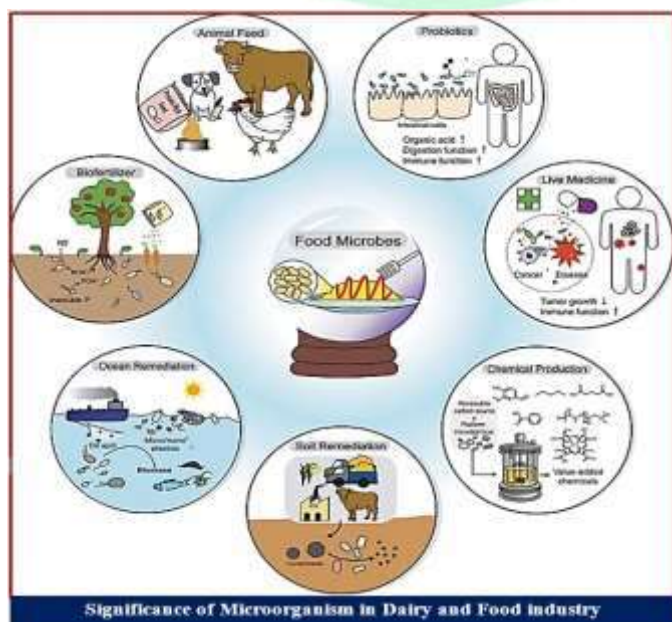
Role of Microbes in Food Industries

Microorganisms have many excellent uses in the food sector outside of agriculture. The quantity and quality of food produced are greatly influenced by bacteria. Pasteurized milk is inoculated with a particular culture of bacteria to cause fermentation. Yogurt and cheese are two of the various fermented goods made from milk. In reality, they are utilized to transform one chemical into another that can be safely consumed. For instance, milk is used to make yogurt and cheese, while sugar is used to make wine and bread.

Yogurt production: Yoghurt is a product obtained from milk which is produced by inoculation of bacterial culture. It can be produced by making the use of any kind of milk but most commonly cow's milk is used. A variety of milk including whole, dried, skimmed, evaporated, or semi-skimmed milk can be used for yogurt production. The lactose, milk sugar, is fermented and produces lactic acid by the bacteria including *Streptococcus salivarius*, *Streptococcus thermophiles*, and *Lactobacillus bulgaricus*. These bacteria are also called Lactic Acid Bacteria or LAB, collectively (Oyeleke, 2017). The bacteria feed on lactose present in milk and release lactic acid as their waste product of feeding process. The increase in acidity of yogurt due to lactic acid formation is also beneficial to prevent the proliferation of other potentially pathogenic bacteria. Both pasteurized and unpasteurized milk can be used for yoghurt formation. For complete fermentation, two or more bacterial cultures can be used together.

Cheese production: Cheese is formed by inoculation of milk with a microbial culture containing specific microorganisms. Cheese is a solid food can be made from the milk of several animals, although cow's milk is the most popular. You can also utilize milk from water buffalo, sheep, goats, and reindeer. Lactic acid, which gives milk its sour flavor, is produced when bacterial cultures are used to ferment milk. Casein, or milk protein, coagulates as a result. There are several types of cheese. On the bases of microbes added, cheese is of following types:

- ✓ Cheddar cheese is prepared by using bacteria to



increase its flavor and texture.

- ✓ Swiss cheese is prepared by using *Propionibacterium shermanii*.
- ✓ Camembert cheese is produced by using the combination of both bacteria and fungi.
- ✓ Roquefort cheese and blue cheese is produced by using of mold fungi.

Bread production: Yeast is a single-celled, saprotrophic fungus. The yeast cells digest food that has sugar and minerals by secretion of enzymes. Yeast is used for production of bread. Carbon dioxide is produced when yeast culture is added to flour and water, and this carbon dioxide is trapped in the flour-based dough. The dough is raised by CO₂ to make bread. The most common type of flour is wheat flour, which includes starch. Starch serves as the yeast's energy source.

Chocolate production: Microbes are used in the production of chocolate. The seeds of cacao trees are actually the source of chocolate. The white, meaty pods of cocoa trees contain these seeds. The pods are first fermented using naturally occurring microbes, primarily yeasts and bacteria like *Lactobacilli* and *Acetobacter*, in order to extract the seeds. When the temperature rises throughout the fermentation process, these microorganisms make ethanol from yeast, which kills the beans and contributes to the chocolate's flavor.

Conclusion

Land resources are under tremendous strain to maintain food security as the world's population grows at an exponential rate. There may be detrimen-

tal effects on the ecology if forest areas are used for agriculture. An essential component of the soil ecology, microbes are crucial to raising crop yields. The most well-known and quickly expanding area of the biological sciences is biotechnology, which has a wide range of applications in sustainable agriculture. Among the products of biotechnology that are crucial to sustainable agriculture are biofertilizers, biopesticides, bioherbicides, bioinsecticides and numerous additional fungal and viral insecticides made using microorganisms. Microbial fermentation is also used to produce a number of other significant food items. At particular stages of the food manufacturing process, various micro-organisms are added to achieve the intended impact of food.

References

- Andreote, F. D., Gumiore, T. and Durrer, A. (2014). Exploring interactions of plant microbiomes. *Scientia Agrícola*, 71: 528-539.
- Kapoor, D., Sharma, P., Sharma, M. M. M., Kumari, A. and Kumar, R. (2020). Microbes in pharmaceutical industry. In *Microbial diversity, interventions and scope* (pp. 259-299). Singapore: Springer Singapore.
- Mohammadi, K. and Sohrabi, Y. (2012). Bacterial biofertilizers for sustainable crop production: a review. *ARPN Journal of Agriculture and Biological Sciences*, 7(5): 307-316.
- Oyeleke, S. B. (2009). Microbial assessment of some commercially prepared yoghurt retailed in Minna, Niger State. *African Journal of Microbiology Research*, 3(5): 245-248.

- Schmeisser, C., Steele, H. and Streit, W. R. (2007). Metagenomics, biotechnology with non-culturable microbes. *Applied Microbiology and Biotechnology*, 75(5): 955-962.
- Taylor, M. D., Klaine, S. J., Carvalho, F. P., Barcelo, D. and Everaarts, J. (Eds.). (2002). *Pesticide Residues in Coastal Tropical Ecosystems: Distribution, Fate and Effects*. CRC Press.
- Zimmermann, G. (2007). Review on safety of the entomopathogenic fungus *Metarhizium anisopliae*. *Biocontrol Science and Technology*, 17(9): 879-920.



Role of Microplastics in Neurobehavioral Disorders

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Introduction

Because of their widespread occurrence and potential to affect human health, microplastics (MPs) and nanoplastics (NPs) constitute a class of environmental contaminants of growing concern. They are defined as plastic particles with a diameter of less than 5 μm and 100 nm, respectively. They differ from macroplastics ($>5\text{ mm}$), which are visible debris that are frequently left out of MPs/NPs studies (Baroni *et al.*, 2025). Personal care goods, synthetic fibers, and packaging materials are frequent sources of these tiny particles, which mostly come from the breakdown of bigger plastic objects or industrial manufacturing releases. Notably, even at submicron sizes, MPs can build up in tissues like the brain. Secondary microplastics, however, result from the breakdown of larger plastic debris through environmental weathering, including UV radiation, wave action, and abrasion. These fragmentation processes yield progressively smaller particles, contributing significantly to environmental contamination. Additionally, the washing of synthetic textiles releases microfibers, a prevalent form of secondary microplastic. The effects vary depending on the biological model, dose, and particle characteristics; reported thresholds range from tens of nanometers to several

hundred nanometers. However, there is no universal detrimental size threshold. According to research, MPs have been widely found in a variety of habitats, including freshwater, marine, and terrestrial settings, with concentrations in some areas reaching alarming proportions. Even the most isolated environments, such a remote high-altitude lake in China's Tibetan Plateau, have been discovered to have MP infiltration, with MP levels in surface water as high as 5.56 items L^{-1} (Liang *et al.*, 2024). In addition to posing a hazard to aquatic life, this pervasive environmental contamination may have an effect on human health through the food chain, especially when seafood is consumed. Due to their minuscule size, MPs and NPs are hypothesized to traverse biological barriers, including the blood-brain barrier, infiltrate cellular interiors and potentially exert direct cytotoxic effects. Neurobehavioral disorders, including anxiety, depression, cognitive impairment, autism spectrum disorder (ASD), and attention deficit hyperactivity disorder (ADHD), represent a significant global health burden. Anxiety, depression and cognitive impairment primarily affect emotional wellbeing and cognitive function, often stemming from neurobiological dysregulations such as neurotransmitter imbalances & neuroendocrine disruptions.

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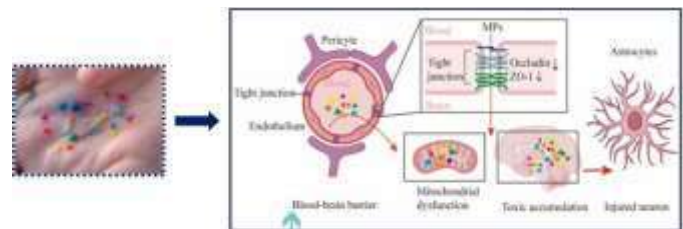
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Neurobehavioral disorders induced by MPs

Anxiety and depression: Substantial evidence from animal models links MPs exposure to the development of anxiety and depression-like behaviors. The impact of MPs on emotional cognition in animals, particularly concerning behavioral modifications, reveals substantial disruption to the nervous system. In vivo studies using zebrafish, which exhibit a 70% genetic homology with humans, serve as an effective model for such studies. Microplastics also influence mood-regulating regions of the brain. Notable reductions in dendritic length and spine density in the PFC have been documented following exposure to PS MPs, leading to compromised neuronal connectivity (Suman *et al.*, 2024). Damage to the PFC, a region essential for executive functioning and emotional regulation, may precipitate behavioral changes and cognitive deficits. Furthermore, a decrease in neuronal cell populations in the hippocampal dentate gyrus and hippocampal horn has been connected to exposure to PS-MPs, which may affect memory and emotional reactions. The amygdala and hypothalamus have also shown signs of neuronal degeneration, which further affects emotional control (Kaur *et al.*, 2024). Together, these results from animal models imply that MPs may interfere with emotional regulation by affecting the structure and function of neurons in important brain regions, which could lead to neurobehavioral disorders including sadness and anxiety.

Cognitive impairment: Exposure to microplastics is reliably linked to cognitive impairments in a variety

of experimental paradigms. Research on animals has shown that MPs interfere with memory and learning processes. The water maze test revealed that exposure to PS-MPs caused neurobehavioral alterations in mice, including longer delay to reach a platform and decreased spatial learning and cognitive function. In zebrafish models, prolonged exposure to polyglycolic acid (PGA) has been shown to alter 5-HT levels in the brain via the gut-liver-brain axis, significantly diminishing motor performance and inducing cognitive deficits (Luan *et al.*, 2024). Tentative connections to human disease are provided by epidemiological studies and research on neurodegenerative hallmarks. The frequency of micronuclei (MN), nucleoplasmic bridge (NPB), and nucleoblast bud (NBUD) development in human peripheral blood lymphocytes after exposure to PE-MPs has been found to significantly increase in epidemiological investigations. These measurements' rise has been connected to neurodegenerative conditions including Parkinson's and Alzheimer's disease, offering fresh perspectives on the processes behind cognitive decline. Notably, compared to normal brain samples, the concentration of MPs in brain samples from dementia patients was found to be substantially greater.



Autism spectrum disorder (ASD), and Attention deficit hyperactivity disorder (ADHD)

Recent research has indicated a potential link between prenatal and early postnatal exposure to MPs and the subsequent development of ASD and ADHD-like phenotypes in animal models. Zaheer *et al.* (2022) found that prenatal exposure to PE in C57BL/6J mice leads to traits similar to autism spectrum disorder, and resulting in decreased social interaction and repetitive behaviors in animal models. Following PE exposure, dysbiosis of the microbiota and increased levels of EGR-1 and ACR genes may be signs of ASD-like traits. Additionally, research using zebrafish in vivo has demonstrated that early exposure to MPs causes considerable DNA demethylation in adult stages with an overexpression of genes linked to neurotoxicity, including *oxtrl* and *slc6a4b*. Research utilizing rodent models has shown that NPs and MPs can be transferred across the placenta and through lactation, leading to their accumulation in the brains of fetuses and neonates. This accumulation has been found to disrupt the levels of cerebral monoamine neurotransmitters and the signaling of amino acids in the hippocampus. Prenatal exposure to these substances results in cortical thinning and hyper proliferation in fetal rats, while not affecting neuronal differentiation.

Recommendations and measures to reduce MPs pollution

Establishing a coordinated framework targeted at reducing exposure hazards through a multifaceted strategy is crucial to mitigating and managing microplastic contamination. Microplastic levels in bottled water can be three to five times

greater than those in tap water, and research shows a significant association between the concentration of MPs in feces and the frequency of using takeout containers. At the individual level, it is essential to prioritize the usage of stainless steel or glass containers over disposable dinnerware and to encourage the simultaneous utilization of community tap water systems with residential water filtration devices. A dynamic monitoring network for MPs in drinking water should be established, and the water delivery infrastructure should gradually replace outdated PE pipes with food-grade stainless steel components. MP concentrations are noticeably higher indoors than outdoors. The potential release of microplastics from materials including ornamental tiles, insulating foam wallpaper, and sheet paper rises when exposed to UV radiation. In comparison, the average change in tiles and paints is rather minimal. In addition to establishing environmental criteria for sporting facilities, such as the use of recycled polyester fiber in sportswear, municipalities can encourage the use of rubber-modified asphalt for roads. The study and development of bio-based tires should be accelerated by the industrial sector; dandelion rubber tire prototypes are presently being tested.

Conclusion

Numerous studies conducted in the last ten years have demonstrated the harmful effects of exposure to MPs and NPs on human health. When the data from different biological complexity levels are combined, it creates a troubling but rational

picture. In vitro research has been crucial in determining basic mechanisms of toxicity at the molecular and cellular level. It has shown that MPs/NPs can cause oxidative stress, mitochondrial dysfunction, and inflammatory reactions in neural cells, as well as jeopardize the blood-brain barrier. In conclusion, there is a real and serious risk to neurological health due to the increasing occurrence of MPs in the environment, which may have implications for neurobehavioral diseases.

References

- Zaheer, J., Kim, H., Ko, I. O., Jo, E. K., Choi, E. J., Lee, H. J., ... and Kim, J. S. (2022). Pre/post-natal exposure to microplastic as a potential risk factor for autism spectrum disorder. *Environment International*, 161: 107121.
- Baroni, A., Moulton, C., Cristina, M., Sansone, L., Belli, M. and Tasciotti, E. (2025). Nano-and microplastics in the brain: An emerging threat to neural health. *Nanomaterials*, 15(17): 1361.
- Suman, A., Mahapatra, A., Gupta, P., Ray, S. S. and Singh, R. K. (2024). Polystyrene microplastics induced disturbances in neuronal arborization and dendritic spine density in mice prefrontal cortex. *Chemosphere*, 351.
- Kaur, M., Sharma, A., John, P. and Bhatnagar, P. (2024). Manifestation of polystyrene microplastic accumulation in brain with emphasis on morphometric and histopathological changes in limbic areas of Swiss albino mice. *Neurotoxicology*, 105: 231-246.
- Liang, T., Ho, Y. W., Wang, Q., Wang, P., Sun, S., Fang, J. K. H. and Liu, X. (2024). Distribution and risk assessment of microplastics in water, sediment and brine shrimps in a remote salt lake on the Tibetan Plateau, China. *Journal of Hazardous Materials*, 476: 134959.

Botrytis Blight of Tulip: A Threats to Tulip Grower

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Introduction

Tulip (*Tulipa gesneriana* Linn.), the premier ornamental flowering bulb, belongs to family Liliaceae. It is one of the commercially important bulbous ornamental plants owing to its unsurpassed beauty and economic value (Nisa *et al.*, 2022). It is consistently ranked behind rose, chrysanthemum and carnation in the world cut flower trade but is ahead of gladiolus in Netherlands. The tulip, which is native to Central Asia was likely to be first cultivated in Persia in the 12th century. In India's hilly provinces, such as Jammu and Kashmir and Himachal Pradesh, tulips thrive, but they don't do well on the plains. Premium cut flowers are grown in glass greenhouses in Himachal Pradesh, however it is more economical to sow bulbs in the field. The establishment of the Indra Gandhi Memorial Tulip Garden in Srinagar, which is the largest tulip garden in Asia and spans 40 hectares of land, is proof that the Kashmir valley has enormous potential for tulip production due to its ideal climate and soil fertility. The production of tulip are threatened by several bacterial, fungal and viral diseases. *Botrytis tulipae* and *B. cinerea* are fungi that cause “tulip fire” and “gray mold”, respectively, in tulip plants. *B. tulipae*

induces lesion formation on the leaves, flowers and bulbs of the tulip. On leaves, infection appears as minute lesions or spots that are yellow to light brown in color. As these lesions enlarge, they become slightly depressed and turn gray with a brown border. The causal agent of gray mold, *B. cinerea*, induces lesions on the leaves, stems and flowers. Water-soaked lesions initially appear at the top and the edge of tulip leaves, and subsequently become larger and necrotic (Nishimura, 1988). The lesions caused by *B. cinerea* are very difficult to distinguish from those caused by *B. tulipae*. It is a common disease in greenhouses, as environmental conditions in these structures are often ideal for infection. During periods of high humidity and/or rain, crops in commercial fields and residential plantings may also be at risk. In addition, Botrytis blight can result in decay of stored produce, and in the case of hemp, may damage floral material. Numerous species of the Botrytis fungus have been linked to Botrytis blight disease. While some species, such as *Botrytis cinerea*, have a very wide host range, others are host-specific. Examples of some host-specific species include *B. allii* (onion neck rot), *B. squamosa* (onion leaf blight/blast), *B. tulipae* (tulip fire), *B. paeoniae*

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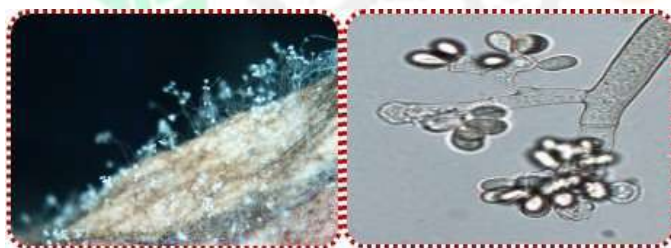
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(gray mold of peony), and *B. gladiolorum* (gladiolus gray mold).

Pathogen Morphology

Botrytis tulipae, the fungal pathogen responsible for Botrytis blight of tulip, exhibits characteristic morphological features. The fungus produces conidiophores with branched hyphae, bearing clusters of conidia (spores) on swollen tips. Conidia are typically ovoid to ellipsoid, hyaline to pale brown, and measure $7-15 \times 5-7 \mu\text{m}$ (Hsiang and Chua, 2007). *B. tulipae* also produces sclerotia, dormant structures that overwinter in soil or on infected debris, which are irregularly shaped, black, and 1-5 mm in diameter (Lorbeer *et al.*, 2007). Understanding the morphology of *B. tulipae* aids in diagnosis and helps distinguish it from other Botrytis species.



Symptoms

On leaves, there are tiny, yellowish dots that are encircled by a darker, water-soaked area and somewhat extended in the direction of the leaf veins. The lesions give the leaf a speckled appearance and are slightly sunken. As the lesions get bigger, they get more depressed and turn brown or white gray in hue. The lesions' borders are fairly clear at this point. Eventually, the entire leaf may be affected by the lesions as they grow and unite. The leaf folds and bends to one side when an infection develops on the

leaf margin close to the tip. The term “fire” comes from the fact that newly developed leaves and shoots on plants that were infected the year before may be deformed or appear burned. Lesions on stems resemble those on leaves but are more elongate and more depressed. A lesion may extend through the stem, causing it to weaken and break at the point of the attack. On flowers, infections appear as minute lesions or spots that are whitish to light brown. After the lesions enlarge, they turn a deeper brown and may involve the tissue that surrounds the base of the petals. This tissue becomes dry and wrinkled. Blighting may also take place when the flower is still in the bud and prevent the bud from opening.



Diseases cycle

The disease cycle of Botrytis blight of tulip, caused by *Botrytis tulipae*, involves several stages. The pathogen overwinters as sclerotia in soil or on infected plant debris. In spring, sclerotia produce apothecia, which release ascospores. These ascospores are the primary inoculum and infect tulip tissues, especially during cool, wet weather (10-20°C, 90-100% RH). Infection typically occurs through wounds or natural openings on leaves, stems, and flowers. The fungal mycelium colonizes

plant tissues, producing conidia (spores) on conidio-phores. Conidia are dispersed by wind, water, or insects, infecting other plants. The disease develops rapidly under favorable conditions, with symptoms appearing within 3-5 days. The pathogen can also produce sclerotia on infected tissues, which fall to the ground and serve as a source of inoculum for future infections. Infected bulbs can also harbor the pathogen, allowing it to survive and infect new growth in subsequent seasons. The disease cycle is influenced by environmental factors, such as temperature, humidity, and moisture. Cool, wet weather favors disease development, while dry conditions inhibit the pathogen. The presence of free water on plant surfaces is essential for spore germination and infection. In addition to tulips, *Botrytis tulipae* can infect other plants, including lilies and irises. The pathogen's ability to infect multiple hosts and survive in various environments makes it a significant threat to ornamental crops. Understanding the disease cycle is crucial for developing effective management strategies.

Epidemiology of Disease

High humidity (heavy fog or dew, light drizzly rain) is essential for sporulation and spread. Anything that retards air movement will favor infection, whether from crowded plantings, excessive weeds, or poor locations (Kubota and Abiko, 2002). The fungus is active over a fairly wide temperature range with sporulation occurring between 5 and 27°C (81 °F). The optimum temperature for growth in vitro is 20°C (68°F).

Spores may survive for 6 months when dry and sclerotia for 18 months when dry, but usually survival is shorter when moisture is present as in soil (Hsiang and Chua, 2007). More infection occurs when shoot growth is retarded by low temperatures and in heavy, wet soils. Plant injury from any cause, particularly from hail, will facilitate infection. The continued culture of tulips increases losses because of a build-up of the fungus in debris. Fireheads act as the primary source of spores for early spread of the disease. Splashing raindrops are mainly responsible for this initial spread. Later, wind-blown as well as water splashed spores are involved.

Management Practices

- ✓ Select planting sites with good air movement.
- ✓ Ventilate greenhouses and high tunnels to increase air movement and to keep humidity levels below 80%. Open vents or use fans as needed.
- ✓ Provide adequate spacing between plants; thin plants as needed.
- ✓ Avoid overhead irrigation.
- ✓ Avoid irrigating late in the evening to ensure leaves are completely dry.
- ✓ Avoid excess nitrogen applications, which promote the development of succulent tissues susceptible to infection.
- ✓ Remove dead, damaged, and senescing tissues (such as spent flowers) that can provide an initial food base for the *Botrytis* fungi.
- ✓ Diseased plant tissues and, if required, entire plants should be removed and destroyed.

- ✓ Diseased material should not be composted.
- ✓ Use proper pruning and pinching techniques; avoid tearing and excess wounding.
- ✓ Clean greenhouse surfaces (such as floors and woven weed mat) by sweeping. Wash benches, floors, and tools as needed and between crops. See sanitation and disinfection publications in Additional Resources.
- ✓ Harvest ripe fruit promptly and handle with care to prevent bruising.
- ✓ Store produce immediately after harvest at recommended temperatures and humidity. Hemp should be stored in a cool, dry location.
- ✓ Disease management can be aided by applying contact or systemic fungicides to protect healthy tissues from infection. To reduce the possibility of resistance development, alternate between fungicides in different chemical groups (FRAC code). Before applying fungicides, remove diseased plant parts and thin plants as needed. Soil drenching with mancozeb (0.25%) before shoot emergence helps to prevent further development.

Conclusion

In conclusion, Botrytis blight of tulip, caused by *Botrytis tulipae*, is a significant disease affecting tulip crops worldwide. The disease cycle involves overwintering sclerotia, ascospore production, and conidial dispersal, leading to infections and symptom development. Cool, wet weather favors disease development, and the pathogen's ability to infect multiple hosts and survive in various environments

makes it a significant threat. Effective management strategies, including sanitation, cultural practices, and fungicides, can help control the disease. Understanding the disease cycle is crucial for developing integrated pest management (IPM) strategies to minimize the impact of *Botrytis tulipae* on tulip crops. By combining multiple control methods, growers can reduce the risk of disease and promote healthy, disease-free tulips.

References

- Nisa, Q., Shahnaz, E., Banday, S., Anwar, A., Masoodi, K. Z., Hamid, A, *et al.* (2022). First Report of *Fusarium Solani* Associated with the Bulb Rot of Tulip (*Tulipa spp.*) in India. *Plant Diseases*, 106(2): 759.
- Nishimura, J. 1988. Plant Diseases in Japan. Zenkoku Noson Kyoiku Kyokai Publishing Co., Ltd., Tokyo. p.599.
- Hsiang, T. and Chua, L. (2007). Effect of temperature and moisture on the infection of tulip by *Botrytis tulipae*. *Plant Pathology*, 56(3): 441-447.
- Kubota, M. and Abiko, K. (2002). Dispersal of conidia of *Botrytis tulipae* in a tulip field. *Annals of the Phytopathological Society of Japan*, 68(2): 133-138.
- Hsiang, T. and Chua, L. (2007). Effect of temperature and moisture on the infection of tulip by *Botrytis tulipae*. *Plant Pathology*, 56(3): 441-447.

Purpureocillium lilacinum: A Potential Biological Nematicide

M. S. Siddiqui, Ashok Kumar Koshariya and Nataraja K. D.

Introduction

Phytoparasitic nematodes, consisting of destructive genera such as *Meloidogyne incognita* (root-knot nematode) and *Globodera rostochiensis* (potato cyst nematode), impose a staggering estimated annual economic loss of 157 billion dollars on worldwide agricultural productivity. These microscopic creatures infiltrate root systems, eliciting galling, nutrient malabsorption, and physiological stress that culminate in substantial yield reductions, often exceeding 50% in vulnerable monocultures like tomatoes, soybeans, and cotton. This pervasive threat not only undermines food security but also exacerbates socioeconomic disparities in developing regions, compelling the agronomic community to prioritise sustainable, resilient nematode management paradigms (Rigobelo *et al.*, 2024). Preeminent among these innovative bio-control modalities stands *Purpureocillium lilacinus*, an indigenous soil-borne fungal endophyte with potent nematicidal attributes. This naturally occurring agent proffers agricultural practitioners an ecologically safe and empirically validated alternative to conventional synthetic nematicides, which are increasingly encumbered by issues of environmental

persistence, non-target toxicity, and evolving resistance profiles. *Purpureocillium lilacinum* is a cosmopolitan soil fungus that has evolved into a highly adapted parasite of nematode eggs and juvenile stages. While historically categorized within the genus *Paecilomyces*, a nomenclature that persists in many commercial agricultural circles, it is formally recognised today as *Purpureocillium lilacinum*. As a naturally occurring inhabitant of agricultural landscapes, this microorganism has been the subject of rigorous scientific scrutiny for more than thirty years due to its efficacy as a biological control agent. Its inherent resilience across diverse pedological conditions and environmental zones allows for successful integration into various farming systems. Commercial products, which generally feature spore concentrations between 1×10^8 and 1×10^9 CFU per gram, offer a dependable means of nematode suppression when utilised through evidence-based application methods (Rigobelo *et al.*, 2024).

Several distinctive physiological traits underpin the effectiveness of this fungus against plant-parasitic nematodes. It develops specialized infection structures known as appressoria, which

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facilitate secure attachment to the host, concurrently releasing a suite of lytic enzymes such as chitinase, protease, and beta-1,3 glucanases to compromise the nematode's structural defenses and eggshells. Notably, the fungus exhibits high host specificity; it selectively impacts nematodes while remaining innocuous to beneficial soil microbes, plants, and human health. Furthermore, its capacity to proliferate within the remains of its host establishes a self-perpetuating cycle of biological control within the soil ecosystem.

The biocontrol efficacy of *Purpureocillium lilacinum* is driven by a multi-faceted mode of action: the secretion of chitinolytic and proteolytic enzymes to dissolve nematode cuticles; the production of adhesive conidia and appressoria for the direct invasion of eggs and colonization of juveniles; and the rapid expansion of fungal hyphae through host tissue to diminish population growth. In contrast to synthetic chemical treatments, this fungus targets specific pathogens while maintaining the integrity of the soil microbiome, thereby enhancing biodiversity and sustained fertility. Whether delivered via granular soil treatments, seed dressings, or liquid drip-irrigation systems, its flexible application within Integrated Pest Management (IPM) frameworks has consistently produced results in field trials, showing nematode population decreases of 25-40% alongside measurable increases in crop productivity. As global regulations tighten on conventional chemical pesticides, this fungal agent represents a new era of precision biological control,

protecting agricultural yields while minimizing the environmental impact (Rigobelo *et al.*, 2024).



Purpureocillium lilacinum culture, conidiophores, phialides and conidia

Mode of Action: How *Purpureocillium lilacinum*, Controls Nematodes

The fungus employs a sophisticated multi-step process that ensures comprehensive nematode control.

Detection and Stealthy Attachment: The offensive begins with chemotaxis. *P. lilacinum* spores act as biological sensors, detecting chemical signatures emitted by nematode eggs, larvae, or mature females within the soil. Once a target is identified, the spores germinate, extending “hunting” hyphae that navigate directly toward the host.

Anchor Formation and Mechanical Breach: Upon contact, the fungus develops specialized anchoring organs called appressoria. These structures act like biological grappling hooks, locking the fungus onto the nematode's exterior. This firm attachment provides the stable platform required for the fungus to begin its biochemical siege on the host's protective armor.

The Biochemical Assault: Enzyme Deployment

To bypass the nematode's tough defenses, *P. lilacinum* secretes a devastating cocktail of degradative enzymes that dissolve structural integrity:

Chitinases: These specifically dissolve the chitin found in eggshells and cuticles.

Proteases: These dismantle the essential protein frameworks of the nematode's body.

Beta-1,3-glucanase: This enzyme breaks down glucan polymers, creating a pathway for deep fungal infiltration.

Internal Infiltration and Host Fatality

Once the exterior is compromised, fungal hyphae flood the nematode's internal cavity to extract vital nutrients. During this colonization, the fungus may also release neurotropic toxins that induce paralysis. This dual-threat of nutrient depletion and toxic shock typically results in the host's death within 24 to 72 hours.

Beyond Defense: Cultivating Plant Vitality

P. lilacinum is more than a biological pesticide; it is a growth catalyst. Research (Shi *et al.*, 2024) indicates that treated crops often exhibit superior root architecture, leading to enhanced water and nutrient absorption. This translates to measurable increases in total biomass and overall vegetative strength. Furthermore, the fungus "primes" the plant's internal security. By triggering the jasmonic acid pathway, it induces systemic resistance, effectively fortifying the plant against a wider spectrum of environmental stressors and secondary pathogens (Ayaz *et al.*, 2024).

Agricultural Benefits of using *Purpureocillium lilacinum*

The adoption of *Purpureocillium lilacinum*, in agricultural systems provides multiple benefits

that extend far beyond simple nematode control. These advantages make it an essential component of sustainable farming practices.

- ✓ Comprehensive Nematode Control
- ✓ Enhanced Plant Growth and Development
- ✓ Soil Health Improvement
- ✓ Economic and Environmental Sustainability

Application Strategies and Techniques

The successful deployment of *Purpureocillium lilacinum* necessitates precise application methods and strategic timing to ensure maximum efficacy. Adhering to these optimized protocols guarantees consistent performance across various agricultural landscapes and soil types.

Soil Application Methods

Soil Drenching: This remains the most prevalent and effective technique. By mixing the specified dosage with water and applying it directly to the soil surface followed by immediate irrigation spores are effectively transported into the critical root zone.

Drip Irrigation: These systems offer superior spore distribution with minimal labor. To maintain system integrity, the solution must be filtered of insoluble particles before being added to irrigation tanks. For best results, apply during the cooler morning or evening hours to preserve spore viability.

Broadcast Application: A method utilized for broad-area coverage to ensure the bioagent is integrated across the field.

Optimal Environmental Parameters

The activity and establishment of this bioagent are heavily influenced by environmental

variables. Monitoring these factors is essential for successful colonization.

Soil Temperature: Thermal conditions significantly dictate fungal behavior. Applications should occur when soil temperatures are between 21-27°C. Because the fungus becomes inactive above 37°C, timing is particularly critical in arid or hot climates (Pscheidt and Ocamb, 2026).

Soil Moisture: Levels should be maintained at 50-75% of field capacity during and after treatment. While sufficient moisture facilitates spore germination, excessive saturation can diminish efficacy. Immediate post-treatment irrigation is recommended to activate the fungus (Pscheidt and Ocamb, 2026).

Weather Considerations: Avoid application during periods of drought, heavy rainfall, or intense UV exposure. Early-morning or late-afternoon windows protect spores from radiation damage and provide a more stable environment for establishment (Pscheidt and Ocamb, 2026).

Environmental Safety and Biodegradability

The ecological profile of *Purpureocillium lilacinum* ensures that its use does not lead to long-term environmental persistence or the accumulation of harmful residues.

Biodegradable Nature: The fungus naturally decomposes within weeks of application. This rapid breakdown prevents groundwater contamination and ensures no toxic buildup remains in the soil or local water systems (Shabrin *et al.*, 2025).

Safety for Non-Target Organisms: Decades of research confirm that this fungus is harmless to

beneficial soil microbes, earthworms, pollinators, and natural pest predators. This high degree of selectivity maintains the natural ecological balance.

Soil Ecosystem Health: Studies indicate that even repeated applications have a minimal negative impact on soil biology. By reducing the reliance on disruptive chemical pesticides, the fungus can actually bolster soil biodiversity and support beneficial microbial communities (Ayaz *et al.*, 2024).

Purpureocillium lilacinum, stands out as an environmentally safe biocontrol agent due to its rapid biodegradability, leaving no persistent residues or risk of groundwater contamination. Decades of research affirm its selectivity, sparing beneficial soil microbes, earthworms, pollinators and pest predators while maintaining ecological balance. Even repeated applications show minimal ecosystem disruption, potentially boosting soil biodiversity by curbing chemical pesticide use. This profile positions it as a sustainable alternative for nematode management, minimizing harm to soil and water systems. Ultimately, its proven safety profile supports broader adoption in eco-friendly agriculture.

References

Ayaz, M., Zhao, J. T., Zhao, W., Chi, Y. K., Ali, Q., Ali, F., Khan, A. R., ... and Huang, W. K. (2024). Biocontrol of plant parasitic nematodes by bacteria and fungi: a multi-omics approach for the exploration of novel nematicides in sustainable agriculture. *Frontiers in Microbiology*, 15: 1433716.

Pscheidt, J. W. and Ocamb, C. M. (Senior Eds.).
(2026). Pacific Northwest Plant Disease
Management Handbook. Oregon State
University.

Rigobelo, E. C., Nicodemo, D., Babalola, O. O. and
Desoignies, N. (2024). *Purpureocillium*
lilacinum as an Agent of Nematode Control
and Plant Growth-Promoting Fungi.
Agronomy, 14: 1225.

Shaili, S. J., Kabiraj, U. K. and Mahedi, M. (2025).
Fungal biocontrol in agriculture: A Sustain-
able alternative to chemical pesticides—a
Comprehensive review. *World Journal of*
Advance Research and Review, 26: 2305-
2316.

Shi, F., Yang, D., Meng, X., Li, J., Zhu, Y. and Liu,
J. (2024). Effects of *Purpureocillium*
lilacinum, and *Bacillus pumilus* on stem
nematode and rhizosphere bacterial commu-
nities of sweet potato. *Scientific Reports*,
14(1): 23290.

Fighting Fungal Fires: New Strategies to Protect Crops from Deadly Diseases

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Introduction

Ensuring global food security is one of the greatest challenges facing humanity in the 21st century. The intensification of world agriculture has to happen in an era, when climate is becoming less predictable, fossil fuel dependency needs to be cut, and cropland and water resources are shrinking or deteriorating. As a result, it is unclear how the growing demand for food can be achieved sustainably. Furthermore, the crops are constantly threatened by pests, pathogens and weeds. Indeed, several studies have estimated that, on average, 20-40% of the potential worldwide crop yield is lost each year due to pests and diseases. Hence, improved crop protection is one of the most important strategies to increase agricultural production and food availability. Most documented fungal species function as obligate saprophytes, while only a small proportion, estimated at under 10%, are capable of colonizing plants. Within this limited group, phytopathogenic fungi constitute an even narrower subset. Despite their relatively low diversity, these pathogens are responsible for major crop disease outbreaks and continue to cause significant, recurring yield losses worldwide. Consequently, they remain a primary focus for researchers, plant breed-

ers and farmers due to their considerable economic impact.

Why fungal diseases demand a new playbook

Fungal phytopathogens are the most destructive agents of agricultural loss, responsible for 20-40 % of global crop reductions and threatening food security for a world population projected to exceed 9 billion by 2050 (FAO, 2019). Traditional reliance on broad-spectrum chemical fungicides has generated three inter-linked problems: rapid evolution of fungicide-resistant pathogen strains, off-target impacts on non-target organisms and ecosystems, and growing regulatory and consumer pressure to reduce pesticide residues (FAO, 2021). The urgency of the situation calls for integrated, ecologically sound strategies that combine genetics, microbiology, chemistry, and digital tools.

Integrated Pest Management (IPM) as the backbone

IPM remains the overarching framework that coordinates multiple control tactics while keeping pesticide use below economic injury levels (FAO, 2021). Its core pillars are given in Table 1.

Host-plant resistance from conventional breeding to CRISPR

Classical resistance sources

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Table 1: Core pillars of IPM

Pillar	Typical Actions	Benefit
Cultural & agronomic	Crop rotation, altered planting dates, sanitation, optimized irrigation	Reduces inoculum sources and creates unfavorable microclimates for spore germination
Genetic resistance	Conventional breeding, marker-assisted selection, genome editing	Provides durable, on-plant protection that lowers chemical inputs
Biological control	Application of antagonistic microbes (e.g., <i>Trichoderma</i> , <i>Bacillus</i>), mycoviruses	Suppresses pathogens via competition, antibiosis, and induced systemic resistance
Chemical & nano-fungicides	Targeted, low-dose synthetic fungicides, nanocarrier formulations	Offers rapid disease knock-down while minimizing drift and residue
Elicitors & RNA-based tools	Chitosan, harpin proteins, spray-induced RNAi (SIGS)	Triggers plant innate immunity and directly silences pathogen genes

Resistance genes (R-genes) such as *Fhb1* in wheat have provided partial protection against Fusarium head blight (FHB) (Su *et al.*, 2019), yet single-gene resistance is often overcome by pathogen evolution. Breeders therefore screen large germplasm collections for quantitative resistance; for example, 22 maize inbred lines displayed stable downy-mildew resistance across nine seasons (Kumar *et al.*, 2020).

Targeted editing of susceptibility (S) genes

A more flexible route is the knock-out or modification of susceptibility (S) genes, which act as host “entry points” for fungi. In wheat, deletion of the start codon of *TaHRC* (an S-gene linked to *Fhb1*) conferred strong FHB resistance (Su *et al.*, 2019). Similar approaches have been described for rice blast (*TaMLO1-5A* in wheat blast) and powdery mildew in grapevine (*VvMLO3*). CRISPR-Cas systems enable precise edits with minimal linkage drag. Recent reviews emphasize that 33 S-genes have already been catalogued in wheat, offering a rich palette for multiplex editing to stack resistance against multiple pathogens (Su *et al.*, 2019). Moreover, CRISPR-edited crops have been shown to retain agronomic performance, as illustrated by wheat lines carrying edited *TaHRC* that exhibit no yield penalty (Su *et al.*,

2019).

Metabolic reinforcement

Resistance can be bolstered by enhancing innate chemical defenses. Metabolomic profiling of MDM-resistant maize revealed 4-9-fold increases in salicylic, p-, o-coumaric, caffeic and ferulic acids, together with elevated flavonoids such as naringenin and catechin (Kumar *et al.*, 2020). These phenolics act as antimicrobial compounds and also prime the plant’s defense signaling networks. Breeding for high basal levels of such metabolites, or engineering their biosynthetic pathways via CRISPR, creates a biochemical “firewall” that slows pathogen colonization.

Breeding for Integrated Pest Management (B-IPM)

The B-IPM concept explicitly aims to co-select traits that improve pathogen resistance and promote beneficial microbial interactions (Panke-Buisse *et al.*, 2015). Eco-evolutionary theory predicts that wild plant populations already harbor trait mosaics that simultaneously deter pathogens and attract mutualists. By identifying compatible trait combinations: e.g., root exudate profiles that favor *Trichoderma* colonization while reducing

Fusarium infection, breeders can develop cultivars that leverage the plant microbiome as a living defense.

Proof-of-concept work in wild strawberry demonstrated that genotypes with strong resistance to *Botrytis cinerea* and *Colletotrichum acutatum* also supported higher colonization by beneficial microbes, suggesting that dual-optimisation is feasible (Panke-Buisse *et al.*, 2015). Translating this to staple crops will require high-throughput phenotyping of both disease scores and microbiome composition, followed by marker-assisted selection for the synergistic trait set.

Biological control agents (BCAs): living antagonists

Fungal antagonists: *Trichoderma* spp. are among the most widely studied BCAs. In vitro, extracts of *T. koningiopsis* T10 inhibited *Neopestalotiopsis rosae* conidia production by >92 % and matched the efficacy of a conventional fungicide under greenhouse conditions. Field trials in maize showed that *Trichoderma* inoculation reduced disease severity of *Peronosclerospora sorghi* by ~20 % when combined with host resistance (Kumar *et al.*, 2020).

Bacterial antagonists: *Bacillus velezensis* and other *Bacillus* spp. produce lipopeptides, siderophores, and enzymes that suppress *Fusarium* wilt, onion basal rot, and other soilborne diseases. Their ability to colonize the rhizosphere and form biofilms makes them effective soil-borne disease suppressors and plant growth promoters.

Yeast and mycoviruses: Yeasts such as *Saccharomyces cerevisiae* and *Candida tropicalis* act as “killer” organisms that secrete volatile organic compounds lethal to pathogens, while mycoviruses can attenuate fungal virulence without external inputs (Ansari *et al.*, 2022). Collectively, BCAs lower pathogen inoculum, stimulate induced systemic resistance (ISR), and reduce the need for chemical sprays. Their integration with resistant cultivars often yields additive disease control, as demonstrated by combined seed-treatment and foliar BCA applications that cut maize downy-mildew incidence by >95 % (Kumar *et al.*, 2020).

Plant-defence elicitors: priming the immune system

Elicitors such as chitosan, harpin proteins, and β -glucans act as danger-associated molecular patterns (DAMPs) that trigger systemic acquired resistance (SAR). Chitosan treatment elevates phenolic content and activity of peroxidase and polyphenol oxidase enzymes, creating a hostile chemical environment for invading fungi (FAO, 2021). Unlike synthetic fungicides, elicitors leave no residue and can be applied repeatedly without selecting for resistant pathogen strains.

Nanotechnology-enabled fungicides: precision delivery

Nanocarriers improve the efficacy, persistence and safety of fungicidal actives. Notable examples are given in Table 2. These systems protect the active ingredient from premature degradation, enable controlled release and reduce off-target drift,

Table 2: Nanotechnology-enabled fungicides

Nano-formulation	Pathogen target	Reported efficacy
Ag@DMSNs-SH (silver-nanoparticle-loaded dendritic mesoporous silica)	<i>Botrytis</i> spp., <i>Fusarium</i> spp.	>70 % mycelial inhibition
Si- or chitosan-nanoparticles (e.g., Pro@CS/PQ)	<i>Rhizoctonia</i> spp., <i>Botrytis</i>	>85 % disease control with minimal phytotoxicity
Polyurea microcapsules of fluazinam	Broad-spectrum	>60 days of protective activity, 30-40 % lower application rates

thereby aligning chemical control with sustainability goals (FAO, 2021).

RNA interference (RNAi) and spray-induced gene silencing (SIGS)

Advances in RNAi-based sprays allow transient, sequence-specific silencing of essential pathogen genes without altering the plant genome. The review by Ansari *et al.* highlights that host-induced and spray-induced gene silencing can suppress fungal virulence factors and reduce disease severity, offering a non-transgenic, environmentally benign control option. Coupled with CRISPR-mediated host edits, RNAi provides a two-pronged molecular blockade: the host is less hospitable, and the pathogen's key effectors are knocked down in real time.

Microbiome engineering and bio-formulations

Manipulating the soil and rhizosphere microbiome creates a living barrier that continuously suppresses pathogens. Strategies include:

- ✓ Inoculation with consortia of *Trichoderma*, *Bacillus*, and arbuscular mycorrhizal fungi that occupy niches otherwise exploitable by pathogens.
- ✓ Pre-biotic amendments (e.g., organic residues rich in phenolics) that selectively foster beneficial taxa.
- ✓ Phage-like mycoviruses that attenuate fungal

aggressiveness.

Field evidence shows that integrating microbiome-engineered soils with resistant cultivars can increase yields by up to 30 % under disease pressure, while also improving nutrient use efficiency (Kumar *et al.*, 2020).

Putting the layers together: a systems view

A multilayered defense schema can be visualized as concentric circles around the plant:

Landscape-level management: Crop rotation, diversified planting, and weather-forecast-driven scouting reduce primary inoculum.

Soil-microbiome conditioning: Application of BCA consortia and organic amendments builds a suppressive community.

Genetic armor: CRISPR-edited S-gene knock-outs and metabolically fortified lines provide intrinsic resistance.

Elicitor priming: Periodic chitosan or harpin sprays keep the plant's immune system on alert.

Targeted chemical/nano interventions: Nano-fungicides applied only when disease thresholds are breached, delivering a rapid "burst" of control.

Molecular knock-down: RNAi sprays applied during high disease risk periods to silence pathogen effectors.

When any single layer fails (e.g., a pathogen evolves fungicide resistance), the remaining layers

Table 3: Future directions and research gaps

Area	Knowledge gap	Suggested research
CRISPR multiplexing	Off-target effects in polyploid crops	Develop high-fidelity Cas variants and robust genotyping pipelines
B-IPM trait discovery	Limited markers linking resistance to microbiome recruitment	Use GWAS coupled with metagenomics to pinpoint co-selected loci
Nano-carrier environmental fate	Long-term soil accumulation and non-target impacts	Conduct lifecycle assessments and biodegradable carrier design
RNAi field stability	Rapid degradation of dsRNA under UV and rain	Formulate dsRNA with protective nanoparticles or clay carriers
Economic feasibility	Cost-benefit analysis for smallholder adoption	Pilot integrated packages in diverse agro-ecologies and model return on investment

continue to suppress disease, preventing catastrophic outbreaks. This redundancy mirrors natural ecosystem resilience and limits the evolutionary pathways available to the pathogen, thereby extending the durability of each control measure.



Fig. 1: Symptoms caused by fungi

Color alterations on grapevine (A-grape downy mildew) and basil (B-basil downy mildew). Shape alterations on peach (C-peach leaf curl). Necrosis on grapevine (D-grape black rot). Fruit rot on an orange (E-rot fungus). Mold on bread (F-black bread mold). Mildew on grapevine (G) and on a weed (H). Botrytis bunch rot on grapevine and strawberry (I,J) and black mold on grapes (K). Apple scab fungus on apples (L) and beech tree dead from dry rot (M), necrosis (N-grape downy mildew). Wilting on grapevine (O-leaf stripe disease). Dry rot fruiting body (P).

Conclusion

Fungal fires can no longer be extinguished by a single fire-hose; they demand a coordinated, multilayered strategy that blends modern genetics, microbial allies, smart chemistries, and ecological stewardship. By editing susceptibility genes, harnessing elite BCAs, priming innate immunity, delivering fungicides via nanocarriers and silencing pathogen genes with RNAi, growers can construct a resilient defense that safeguards yields, protects.

References

- Ansari, M. I., *et al.* (2022). RNA interference and spray-induced gene silencing for crop protection. *Frontiers in Plant Science*, 13: 845-860.
- Panke-Buisse, K., Poole, A. C., Goodrich, J. K., Ley, R. E. and Kao-Kniffin, J. (2015). Selection on soil microbiomes reveals reproducible impacts on plant function. *The ISME Journal*, 9(4): 980-989.
- Su, Z., Bernardo, A., Tian, B., Chen, H., Wang, S., Ma, H. and Bai, G. (2019). A deletion mutation in *TaHRC* confers Fusarium head blight resistance in wheat. *Nature Genetics*, 51(7): 1099-1105.

- Food and Agriculture Organization. (2019). The state of food and agriculture 2019: Moving forward on food loss and waste reduction. FAO.
- Food and Agriculture Organization. (2021). Pesticide use and environmental impact in agriculture. FAO.
- Kumar, B., Singh, R. and Sharma, P. (2020). Integrated disease management in maize using resistant genotypes and biological control agents. *Crop Protection*, 135: 104-115.



Healing Wings: The Fascinating World of Insect Zoopharmacognosy

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Introduction

People worldwide suffer from a variety of diseases, some of which are even deadly. We developed medications and vaccines to keep ourselves safe from such diseases. However, many animals, such as elephants, chimpanzees, dogs, and even insects, demonstrate self-medication behaviors by ingesting or applying natural compounds to prevent or treat ailments. Such techniques are common throughout the animal kingdom, frequently in unexpected ways, even if the majority of the data is still observational. Animals' natural capacity for self-medication is known as zoopharmacognosy (from Greek: zoo = animal, pharmacon = drug, gnosy = knowledge) (Ashwini and Patel, 2022). Daniel H. Janzen, an evolutionary ecologist at the University of Pennsylvania, first proposed the idea in 1978. It describes how animals select and utilize plants, soils, fungi, and insects to treat or prevent disease and parasitism. While early research emphasized primates, birds, and mammals, a growing body of work shows that insects themselves also engage in therapeutic behaviors, expanding zoopharmacognosy beyond vertebrates into the invertebrate world.

Insect self-medication has been documented most clearly in lepidopteran larvae. The tiger moth *Grammia incorrupta* provides a compelling case. Under normal conditions, this moth feeds on herbaceous dicots that supply nutrients in its mesquite-oak savanna habitat. However, when parasitized by tachinid flies such as *Exorista mella* or braconid wasps like *Cotesia phobetri*, the larvae shift their diet to plants including *Crotalaria pumila*, *Estigmene acrea*, and *Senecio longilobus*. These plants lack high nutritional value but are rich in pyrrolizidine alkaloids (PAs). The moth tolerates PAs because it possesses enzymes that detoxify them, whereas the internal parasitoid larvae cannot. By increasing PA intake, the infected caterpillars reduce the number of wasp or fly larvae that successfully develop inside them, improving their own survival. Researchers classify this as true self-medication because PA consumption increases fitness only in parasitized individuals while reducing fitness in healthy ones. This behavior suggests an immune defense strategy layered on top of physiological immunity. The broader concept of zoopharmacognosy recognizes that animals may use insects themselves as medicine.

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Though the term often emphasizes plant use, Rodriguez's definition explicitly includes insects as medicinal materials. Ethnoentomological surveys in South India document traditional human use of insects and insect products for over 15 ailments, including ulcer, rheumatism, asthma, and insect bites. While this reflects human ethnomedicine rather than animal behavior, it illustrates the bioactive potential insects hold, which likely underpins their role in animal self-medication systems. Wild animals have been observed ingesting non-nutritive substances such as toxic plants, clay, or charcoal to combat parasites or toxins. Extending this logic, insects may likewise be selected by animals for secondary compounds that confer antiparasitic or antimicrobial benefits.

Criteria for Self-Medication

An insect has two lines of defence system. First, its cuticle acts as a barrier to keep pathogens away, and second, their immune systems can combat infection if the pathogen penetrates this layer. When neither of these defence systems is effective, an insect can look to its habitats for compounds that will aid to fight against infections. Notably, this behavior differs from the regular dietary requirement consumption. There are four conditions that must be met in order to establish legal self-medication, regardless of whether the substances used are medicinal or preventive in nature (Clayton and Wolfe, 1993).

- ✓ The material in concern needs to be intentionally contacted.

- ✓ One or more parasites must be harmed by the material.
- ✓ Increased host fitness must result from the negative impact on parasites.
- ✓ In the absence of parasites, the material must negatively impact the host.

Modes of Self-Medication

Self-medication can be classified into four categories according to the mode of contact: ingestion, absorption, topical application and proximity.

Ingestion: Nicotine ingested by the tobacco hornworm (*Manduca sexta*) reduces colony growth and toxicity of *Bacillus thuringiensis*, leading to an increase in the survivorship of the hornworm (Krischik *et al.*, 1988).

Absorption: Another possible method of self-medication is the absorption of therapeutic compounds through the skin or mucous membranes. Before consuming *Aspilia* leaves, chimpanzees knead them with their tongues for up to 25 seconds. This may help the leaves absorb Thiarubrine A, a powerful antibiotic used to treat stomach acidity.

Topical Application: A better known example is 'anting' behaviour of birds, during which bird grasps an ant in its bill and rubs it frenetically through its plumage. The fact that birds ant exclusively with ants that secrete acid or other pungent fluids suggests that anting may play some role in ectoparasite defence (Ehrlich *et al.*, 1986).

Proximity: Gall-wasps developing galls benefit indirectly from tannin-rich oak leaves, showing reduced fungal attacks and higher survival rates.

Tannin levels vary among oaks, influencing gall density and wasp diversity. This suggests wasps depend on host tannins for fungal defence, despite no direct contact with the compounds.

Types of Insects Zoopharmacognosy

We can differentiate genuine self-medication behavior from similar phenomena like prophylactic consumption or compensating diet choice by applying the four aforementioned criteria. As stated in criteria 4, the crucial element in differentiating self-medication from other behaviors is if the chemical in question is hazardous to the user. Here, dose-dependency is important since many substances that are harmless or even helpful at small quantities can turn harmful at larger ones. Timing that is, whether the drug is administered before or after infection is another helpful approach to classify these behaviors. Substances used to avoid infection (prophylaxis) may be different from those used to treat an active infection (therapeutic medicine), even though they were not specifically mentioned in the initial criteria (de Roode *et al.*, 2013).

Non-toxic substances that are consumed prophylactically: This category is very wide because it might include almost any item that improves immunity or overall health. Alkaloids in nectar, for example, have been shown in one study to reduce pathogen levels in bumblebees (*Bombus terrestris*) without endangering them. Bees that had previously eaten the excrement of their nestmates developed considerably milder illnesses when infected with the trypanosome parasite *Crithidia bombi* than control

groups.

Non-toxic substances that are consumed therapeutically: When infected individuals consume specific substances without apparent costs, this represents compensatory diet choice. For instance, infected individuals of the beetle (*Tenebrio molitor*) increased protein consumption relative to uninfected individuals, allowing them to offset costs of infection. Notably, higher protein consumption did not negatively affect the fitness of healthy beetles.

Prophylactic self-medication: By collecting antimicrobial or antifungal resins to protect their colonies from bacterial and fungal illnesses, ants and bees demonstrate preventive self-medication. However, each of these insects collects resin at a different time. For instance, wood ants (*Formica paralugubris*) use social prophylaxis to stop bacterial epidemics within their colony by gathering antimicrobial resin from conifers (Castella *et al.*, 2008).

Therapeutic self-medication: Fruit flies are the best illustration of this. These flies come into contact with fermenting foods that make alcohol in their native habitat. High-ethanol diets are avoided by uninfected flies because drinking alcohol lowers their fitness. However, eating food that produces alcohol is a wise choice when parasitoid wasps are around since it helps kill wasp larvae. In this instance, “drunk” flies survive their “sober” counterparts.

Conclusion

Since many food plants also have therapeutic properties and the lines between food and medicine can occasionally be blurred, it can be difficult to

identify intentional self-medication in animals or insects. Animals in their natural environments choose beneficial plants, perhaps for medical purposes problems. Examining this behavior can hasten drug development, particularly in endangered habitats. Animal self-medication provides important insights, just as indigenous wisdom informs human medicine. Researchers must evaluate whether a behavior lowers parasites and increases host fitness before figuring out how the drug functions in order to validate self-medication. In addition to being an intriguing feature of nature, insect self-medication creates new opportunities for drug discovery. Insects are small animals that we frequently consider to be quite basic. Some of our favorite bug zoopharmacognosists may eventually find a medication to treat a human illness.

References

- Ashwini, M. and Patel, D. H. (2022). Insect zoopharmacognosy. *Agriculture and Food: E-Newsletter*, 4(4): 209-212.
- Castella, G., Chapuisat, M. and Christe, P. (2008). Prophylaxis with resin in wood ants. *Animal Behaviour*, 75(4): 1591-1596.
- Clayton, D. H. and Wolfe, N. D. (1993). The adaptive significance of self-medication. *Trends in Ecology & Evolution*, 8(2): 60-63.
- de Roode, J. C. and Hunter, M. D. (2019). Self-medication in insects: when altered behaviors of infected insects are a defense instead of a parasite manipulation. *Current Opinion in Insect Science*, 33: 1-6.
- Ehrlich, P. R., Dobkin, D. S. and Wheye, D. (1986). The adaptive significance of anting. *The Auk*, 103(4): 29.
- Krischik, V. A., Barbosa, P. and Reichelderfer, C. F. (1988). Three trophic level interactions: allelochemicals, *Manduca sexta* (L.) and *Bacillus thuringiensis* var. kurstaki Berliner. *Environmental Entomology*, 17(3): 476-482.
- Singer, M. S., Mace, K. C. and Bernays, E. A. (2009). Self-medication as adaptive plasticity: increased ingestion of plant toxins by parasitized caterpillars. *PloS One*, 4(3): e4796.

Microbial Mix or Match: Optimizing Bioinoculant Design

Raj Umakant Zadke, Ravishankar B. S. and Vinod A. Shinde

Introduction

A focus on sustainable methods has been spurred by growing worldwide issues (such as rising food demands, disadvantages, chemical fertilizer shortages, and climate change). One method that shows promise is the application of microbial inoculants, which are natural products with the ability to maintain several ecosystem services while promoting sustainability. The efficiency of microbial inoculants in boosting plant development, improving soil structure, and optimizing soil physiochemical characteristics is demonstrated by a number of widely recognized techniques. Additionally, several microbial taxa have shown promise in bioremediation activities, such as the synthesis of biosurfactants, the breakdown of hydrocarbons, and the buildup of heavy metals (Wu *et al.*, 2022). Bioinoculants are the beneficial soil amendments that use microbes for promoting plant growth and development. They contain dormant or live cells of the efficient strain of nitrogen-fixing, Hydrogen cyanide and siderophore producing microorganisms (Lalitha, 2017). By transforming scarce nutritional components into available form, interactions between

soil-borne microorganisms and the roots of higher plants are crucial to plant development and growth. Additionally, bioinoculants aid in bioremediation, produce systemic acquired resistance, and generate a homogeneous layer of inoculant over seeds (Dangi *et al.*, 2019). Numerous microbial strains that promote plant development have been found and are employed as bioinoculants, including *Azospirillum*, *Rhizobium*, *Bacillus*, *Pseudomonas*, *mycorrhiza*, *Trichoderma* and yeast. Microbes aid plants in a number of ways. 1. By plant growth-promoting rhizobacteria (PGPRs), which function as bioinoculants 2. By acting as biological control agents and in the phytoremediation process (such as *Bacillus cereus*, *Trichoderma*, and *Pseudomonas*) that shield plants from dangerous organisms and heavy metals; 3. By phytostimulation (phytohormones expressed by microbes like *Azospirillum*) that directly promote the growth of plants. Numerous modern methods, including metabolite formulations, liquid formulations, solid carrier-based formulations, and synthetic polymer-based formulations, are employed for their formulation. Microbial inoculants can also be applied as biofertilizers such as Frankia,

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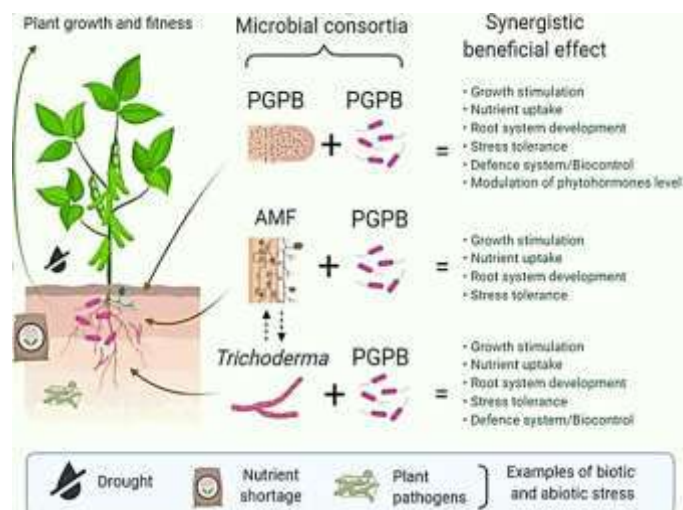
Azospirillum, *Pseudomonas*, *Dyadobacter* etc. using liquid or solid base nutrient medium (Suyal *et al.*, 2016). In the bioformulation process, harmful components are destroyed by the activity of microbial community. Several recent meta-analyses have showed that the majority of commercially accessible products are based on single species and have demonstrated efficacy in accomplishing specified aims after validation. However, the roles and niches that each species can occupy are limited. In the soil environment, this may result in fierce rivalry between the inoculant and native communities, which could lower survival and functionality. As a result, inconsistent conditions and application techniques frequently result in inconsistent microbial inoculant quality and performance. This limits the feasibility of using microbial inoculants extensively (Alori and Babalola, 2018). More sustainable approaches are required, even if these drawbacks can be somewhat offset by mixing other materials, such as chemical fertilizers. The idea of mixing multiple species with complementary traits, known as a consortium, was expanded in the last decade.

Single strain and consortia formulations

One distinct microbe is used in single strain bioformulations to carry out a specific agricultural task. Typically, single strain bioformulations carry out one or more crucial agricultural tasks. Microbial consortia, on the other hand, are collections of many microorganisms that cooperate and perform a wider variety of tasks. These days, microbial consortia are receiving attention.

Advantages of Single Strain Bioformulations

For example, *Rhizobium* fixes nitrogen in legumes, *Azotobacter* fixes nitrogen in non-leguminous crops and mycorrhizal fungi improve phosphorus uptake. These strains usually concentrate on a single core function. These are sensitive to the environment and host-specific. Despite this, single strain bioformulations have a number of benefits, including targeted action and projected performance, which greatly enhance their stability and consistency. It is frequently easier to cultivate and maintain a single strain, which results in a more consistent product. In order to achieve the required results and preserve product integrity over time, it is crucial that each application consistently provides the intended microbiological benefits. Furthermore, single strain formulation is advantageous in the condition where specific microbial functions are required or when the potential interactions between multiples strains are a concern. This approach helpful in minimizing the risk of unforeseen competition or antagonistic effects in multi strain products.



Advantages of Microbial Consortia

The wide range of agricultural operations is the main benefit of microbial consortia. Consortia such as those that combine phosphorus-solubilizing bacteria (Phosphobacteria), growth-promoting fungi (Mycorrhiza) and nitrogen-fixing bacteria (*Rhizobium*, *Azospirillum*), can concurrently address soil fertility and plant health. When several strains work together, they typically produce synergistic effects, where the total benefit exceeds the sum of the individual strains. For instance, using *Azospirillum*, *Pseudomonas*, and *Methylobacterium* together improves plant growth-promoting traits and disease control more effectively than applying them separately. The consortia have better chance to survive in the environmentally diverse conditions because of mutual stimulation and differentiation among the strains. So, they can also help plants to withstand the environmental stresses such as drought and salinity. Microbial consortia have superior capacity in the bioremediation tasks, such as degrading oil contaminants and polycyclic aromatic hydrocarbons in compare to the single strain. Thus, they can also be used for pollution control. The reports shown that inoculation of consortium increases the plant growth by 48% and pollution remediation by 80% in compare to 29% and 48% respectively for the single strain inoculations (Liu *et al.*, 2023). Moreover, the microbial consortia have shown superior performance under the challenging environmental conditions. For example, in the open field drip fertigated tomato production system where pH is high, fertility is low and sandy soil.

Challenges in Bioinoculant Design and Application

Challenges for Single-Strain Inoculants: A single species can only carry out one or a few tasks. Due to fierce competition with natural soil microbial communities, they are also restricted to the ecological niches they can inhabit, which may result in much lower survival rates and decreased functioning. In general, the effectiveness of single strain inoculants varies depending on the application and climatic conditions. A single strain may not be widely used and effective in a variety of crop kinds and environmental circumstances, which restricts their large-scale use. In general, it has been shown that many bioinoculants work effectively in controlled lab settings but fall short in real-world settings. The major cause for bad performance in the field are abiotic stresses like soil pH, temperature, chemical residues and interactions with native microbes (Ganesh *et al.*, 2023). The maintenance and stability of the the strain over longer period of time is also concern.

Challenges for Microbial Consortia: Although microbial consortia have many benefits, using them can be challenging. The intentional disruption of the natural soil microbiome caused by microbial inoculation might result in intricate interactions between the inoculated and native species, producing unpredictable and inaccurate results. A number of variables, including plant type, application techniques and diversity and density, affect the consortia's efficacy. The majority of microbial inoculants

are created via laboratory screening and combination, however it is still very difficult to guarantee their steady survival and functionality in natural settings. Strong research is necessary since greenhouse observations typically do not accurately predict performance under field settings.

Conclusion

Both single-strain inoculants and microbial consortiums hold great promise for improving plant health and agricultural sustainability. Because of their synergistic interactions and wider range of functions, microbial consortia typically outperform single strains in plant growth promotion and bioremediation. However, environmental unpredictability, stability, and interaction with complex soil bacteria present challenges for both formulation development and application. Future studies should concentrate on examining microbial consortia in living soil, investigating the variables that affect inoculation effects, and creating a solid framework for the creation of validating consortia prior to widespread use. Soil physicochemical characteristics, like pH and nutrient content, must be taken into account because they have a big impact on the success of inoculation.

References

- Suyal, D. C., Soni, R., Sai, S. and Goel, R. (2016). Microbial inoculants as biofertilizer. In *Microbial Inoculants in Sustainable Agricultural Productivity: vol. 1: Research Perspectives* (pp. 311-318). New Delhi: Springer India.
- Alori, E. T. and Babalola, O. O. (2018). Microbial inoculants for improving crop quality and human health in Africa. *Frontiers in Microbiology*, 9: 2213.
- Dangi, A. K., Sharma, B., Hill, R. T. and Shukla, P. (2019). Bioremediation through microbes: systems biology and metabolic engineering approach. *Critical Reviews in Biotechnology*, 39(1): 79-98.
- Ganesh, R. S., Kumar, M. N., Kavipriya, J. and Krishnamoorthy, R. (2023). Constrains in Biofertilizer Development and Environmental Factors Influencing its Survival in Soil: A Review. *Agricultural Reviews*, 44(4).
- Lalitha, S. (2017). Plant growth-promoting microbes: a boon for sustainable agriculture. In *Sustainable agriculture towards food security* (pp. 125-158). Singapore: Springer Singapore.
- Liu, X., Mei, S. and Salles, J. F. (2023). Inoculated microbial consortia perform better than single strains in living soil: a meta-analysis. *Applied Soil Ecology*, 190: 105011.
- Wu, Y., Liu, X., Dong, Q., Xiao, M., Li, B., Topalović, O., ... and Wang, C. (2022). Remediation of petroleum hydrocarbons-contaminated soil: Analysis based on Chinese patents. *Chemosphere*, 297: 134173.

The Buzz on Bee Venom: Anticancer Properties Explored

Ojas Chauhan and Ravishankar B. S.

Introduction

Bees are commercially beneficial insects that have been around since the Cretaceous age of the Mesozoic Era. They also help fertilize many different crops. Bees are helpful, but their capacity to administer excruciating and poisonous stings constitutes a risk. Thankfully, most honeybees are not hostile to people and only resort to violence if they perceive danger. *Apis mellifera* is the most often used honeybee species for agricultural pollination globally. All bee products, particularly venom, and honey, have been used for centuries, and their medicinal properties have been described in holy writings such as the Bible and the Quran (Ali, 2024). Bee venom (BV) treatment involves injecting honeybee venom into the human body to cure various ailments. For over 5,000 years, this technique has been used in complementary therapies. It consists of either an indirect implementation, like isolating BV via stimulating electricity and then administering it into the body, or an immediate administration, such as bee stings. The discovery that rheumatism and joint pain are uncommon among beekeepers led to the application of BV in medicine (Ullah *et al.*, 2023). BV has been used in ethnomedicine in many cultures as a natural treatment for a variety of illness.

Because of its anti-inflammatory, pain-relieving, and immune-stimulating qualities, BV has been used in traditional treatments. BV has been utilized in ethnomedical techniques to treat inflammatory diseases, rheumatism, and arthritis. Furthermore, BV has been used to treat skin disorders, wound healing, and even as an antibacterial agent. Bee venom is colourless, scentless liquid of numerous molecules with a slightly acidic pH (4.5-5.5), which bee utilized as protection from enemies. A drop of bee venom comprises 88% water and only 0.1 g dry venom. A gland in the bee's abdominal cavity produces BV, also known as api-toxin. It is made up of a very complex mixture of several physiologically active peptides combinations. Among them are MCD-peptide, melittin, adolapin and apamin. Additionally, it contains potent enzymes such as hyaluronidase, acid phosphodiesterase, phospholipase A2 (PLA2), Enzymes include lysophospholipase and D-glucosidase, as well as naturally occurring amines (such as histamine and adrenaline) and micro-nutrients. A few weeks after metamorphosis, bees have the greatest venom in their glands. As it travels and collects nectar, the amount of poison gradually decreases. When a bee stings, it injects 50-140 µg of venom (Mebs, 2002). The bee stinger has hooks for

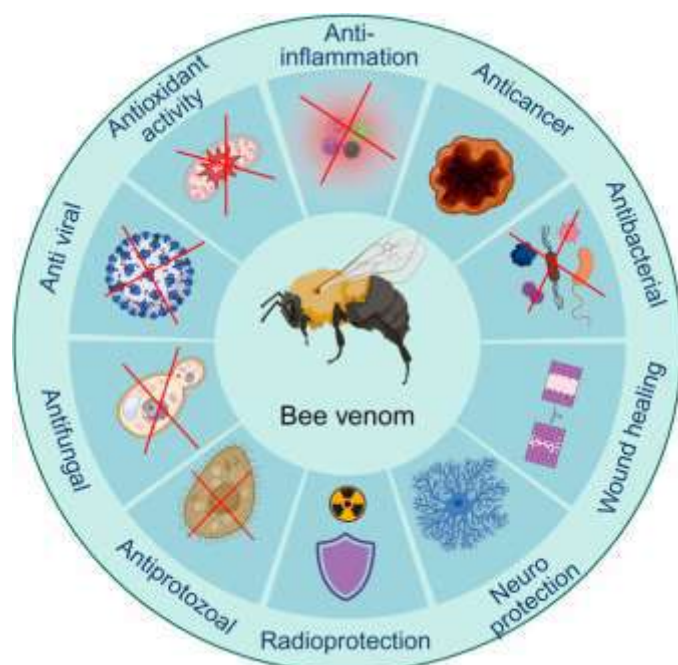
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deeper penetration and stickiness in addition to two parallel needles that release venom into a channel. The stinger, which is located in the abdomen, is ejected when it stings. The stinger and the venom gland remain in the skin of the vertebrate because of its special anatomy, which prevents bees from removing the stinger after a sting. When the muscles holding up the framework break, the bee dies.

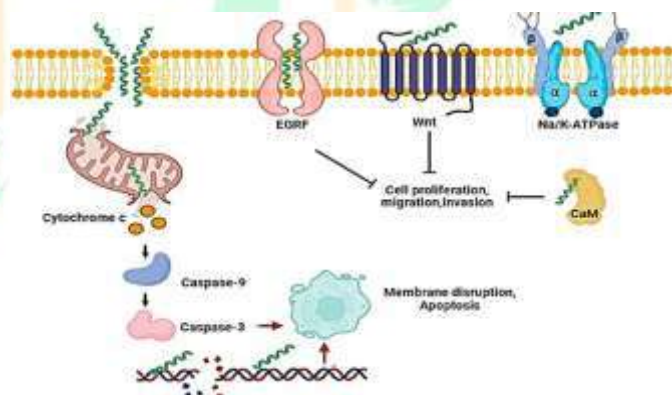


Compound of Bee venom

Melittin: Melittin, a 26-residue peptide, makes up 40-60% of BV and is its primary constituent. The peptide's amino-terminal section is primarily hydrophobic and lacks lytic activity, whereas its carboxyl-terminal part is hydrophilic and produces the lytic action. Melittin is soluble in water in both its monomeric and tetrameric forms due to its amphipathic nature. By rupturing both natural and artificial phospholipid bilayers, it also makes it simple to incorporate melittin into membranes. Melittin's method of action in rupturing membranes

is mediated by pore creation, which lyses both prokaryotic and eukaryotic cells in a non-selective manner, according to earlier research.

Apamin: Apamin is an 18-amino acid peptide containing two disulfide bridges. It is the smallest neurotoxin in bee venom (Son *et al.*, 2007). This polypeptide is able to cross the blood-brain barrier and therefore it affects the central nervous system functioning via different modes of action. For example, it causes neurotoxic effects in the mammalian spinal cord, resulting in hyperactivity and seizures, as it has been shown in rats. By blocking calcium-activated K^+ channels, apamin is also able to affect the permeability of cell membrane toward potassium ions (K^+).



Mast Cell Degranulating (MCD) Peptide: The MCD peptide, often referred to as peptide 401, is a BV polypeptide with 22 amino acids that resembles apamin in structure since both have two disulfide links. It makes up two to three percent of the dry weight of BV (Hanson and Morley, 1974). The physiologic process by which mast cells release histamine is reflected in the name MCD. It is an essential K^+ channel inhibitor, an epileptogenic neurotoxic, and it can significantly lower rats' blood

pressure. Certain MCD biological processes appear to have unique mechanisms and could serve as an excellent example of the structure-function link.

Adolapin: Adolapin is a basic polypeptide with 103 amino acids residues. It corresponds to 1% of the dry weight of BV. Researchers have shown that adolapin possesses anti-inflammatory, anti-nociceptive, and antipyretic effects by blocking prostaglandin synthesis and inhibiting cyclooxygenase activity.

Anticancer Effects of Bee Venom

The anticancer activity of BV against different cancer types and its mode of action are currently the subject of numerous investigations. The primary cause of the anticancer effect is MEL, a basic polypeptide that makes up around half of the dry BV. Havas was among the first scientists to record the impact of BV on cancerous cells. Mufson later noticed that MEL could pass through a phospholipid bilayer, and he linked the relationship between MEL and cell membranes to increased prostaglandin production through arachidonic acid released from phospholipids, impairment of the phospholipid's acyl groups, and increased sensitivity to phospholipid hydrolysis by phospholipase. Additionally, while life expectancy from different illnesses was comparable to that of the general population, beekeepers who were substantially exposed to BV during their working lives had a somewhat reduced incidence of cancer deaths and a much lower rate of death from lung cancer.

Melittin's Anticancer Effect

The inhibitory ability of MEL was first

demonstrated in vitro, where it was proven to be a calmodulin inhibitor that stops human leukemia cells from multiplying and becoming clonogenic. Furthermore, Lee and Hait, for instance, have observed that MEL on astrocytoma cell growth is impeded. According to Hait and Lazo (1986) claims that MEL uses a similar mechanism of action to block calmodulin in leukemia cells. Furthermore, they found that MEL increases bleomycin toxicity in human granulocyte macrophage and erythroid stem cell colonies. Furthermore, Killion and Dunn (1986) demonstrated that leukaemia cells are more dependent on MEL action than conventional mouse lymphoid cells and cells from the bone marrow. This was explained by the fact that bone marrow cells have multiple carbohydrate attachment points on the membrane, which vanish in adult spleen cells and are nearly absent following neoplastic alterations.

Mechanisms of Bee Venom and Melittin Anti-cancer Activity

Drug consumption should therefore be appropriate and targeted. The amphipathic nature of several insect lithic protein molecules, including those extracted from BV, allows them to attach and integrate into negatively charged cell membranes. The membrane potential of cancer cells is higher than that of normal cells (Jang *et al.*, 2003). Consequently, the structural composition of the membrane of malignant tumor cells is especially harmed by some lytic peptides. In contrast to the normal cell membrane. Consequently, MEL ought to play a suitable role in anticancer treatment. Bee venom-

induced apoptosis has been seen both *in vivo* and *in vitro*, indicating that the material is toxic to ovarian cancer cells and that the toxicity is dose-dependent. BV stops the growth of melanoma cancer cells both *in vivo* and *in vitro*. The apoptosis seen in those cells was assumed to be one of the possible mechanisms by which BV decreases proliferation and induces differentiation of those same cells throughout *in vitro*. Furthermore, it was discovered that increased Fas expression in osteosarcoma cells and reduction of cyclooxygenase-2 (COX-2) in lung cancer cells both induced apoptosis (Chen *et al.*, 2004). These results imply that the activation of apoptosis may have an impact on the anticancer effect of BV and MEL, however the precise mechanisms behind this induction are still unknown. In keeping with the growing interest in the possible application of BV peptides in anticancer therapy, it has also been shown that MEL gene therapy induces apoptosis in cancer cells and that these peptides could successfully kill liver carcinoma cells both *in vitro* and *in vivo*. The maturation of moDCs is caused by phospholipase A2 through its activation of enzymes and NF- κ B, activating protein-1, a nuclear component that activated T-cells, according to a prior study in an effort to prevent the synergistic impact between phospholipase A2 (bv-sPLA2) and phosphatidylinositol (3,4)-bisphosphate (PtdIns (3,4) P2) that occurs during the formation of immunostimulatory moDCs driving tumour cell lysis.

Conclusion

For many years, toxins from many animals

have been used in alternative and traditional medicine; the greatest research has been done on the venom of *Apis mellifera*. Numerous studies have examined the benefits of bee venom (BV). Apitherapy is the use of honey and other honey-based products to prevent and treat illnesses. It is mostly based on the experience of using the traditional medical system in diverse ethnic communities. Many studies are now being conducted on BV's anticancer effects, which are primarily attributed to its basic polypeptide melittin (MEL). According to earlier research, BV and its main component, MEL, have a substantial toxic effect on a variety of cancer cells, including those of the liver, lung, my bladder, the kidneys, the prostate, breast, and leukaemia, while normal nontarget cells showed a less noticeable effect.

References

- Ali, A. M. (2024). Advancements in bee venom bioactivities for current therapeutic applications: A Review. *Advancements in Life Sciences*, 11(1): 49-55.
- Ullah, A., Aldakheel, F. M., Anjum, S. I., Raza, G., Khan, S. A. and Gajger, I. T. (2023). Pharmacological properties and therapeutic potential of honey bee venom. *Saudi Pharmaceutical Journal*, 31(1): 96-109.
- Son, D. J., Lee, J. W., Lee, Y. H., Song, H. S., Lee, C. K. and Hong, J. T. (2007). Therapeutic application of anti-arthritis, pain-releasing, and anti-cancer effects of bee venom and its constituent compounds. *Pharmacology & Therapeutics*, 115(2): 246-270.

- Mebs, D. (2002). *Venomous and poisonous animals: a handbook for biologists, toxicologists and toxinologists, physicians and pharmacists*. USA: CRC Press; ISBN 3-88763-093-9.
- Hanson, J. M., Morley, J. and Soria-Herrera, C. (1974). Anti-inflammatory property of 401 (MCD-peptide), a peptide from the venom of the bee *Apis mellifera* (L.). *British Journal of Pharmacology*, 50(3): 383.
- Hait, W. N. and Lazo, J. S. (1986). Calmodulin: a potential target for cancer chemotherapeutic agents. *Journal of Clinical Oncology*, 4(6): 994-1012.
- Jang, M. H., Shin, M. C., Lim, S., Han, S. M., Park, H. J., Shin, I., ... and Kim, C. J. (2003). Bee venom induces apoptosis and inhibits expression of cyclooxygenase-2 mRNA in human lung cancer cell line NCI-H1299. *Journal of Pharmacological Sciences*, 91(2): 95-104.
- Chen, Y. Q., Zhu, Z. A., Hao, Y. Q., Dai, K. R. and Zhang, C. (2004). Effect of melittin on apoptosis and necrosis of U2 OS cells. *Zhong xi yi jie he xue bao= Journal of Chinese Integrative Medicine*, 2(3): 208-209.

Impact of Plastic Waste on Ecosystems and Human Health

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Introduction

Plastics have become indispensable in a variety of industries, such as packaging, construction, industry, transportation, and agriculture, significantly improving modern living. Due to its unique properties, which include resistance, durability, affordability, transparency and lightweight nature, plastic use has grown dramatically since it first hit the market. Plastic pollution has become one of the most pressing environmental issues since the production of disposable plastic products is expanding more quickly than the world can manage. This pollution is most apparent in emerging Asian and African nations since municipal waste collection systems are often inefficient or nonexistent there. With the rise in plastic manufacturing worldwide, plastic degradation has become a serious problem impacting both the environment and public health. Although plastics have made modern life more convenient and adaptable, their durability and resistance to natural deterioration have resulted in ongoing health and environmental issues (Kumar *et al.*, 2021). Because they are composed of intricate polymers, plastics accumulate in ecosystems and

pose a persistent hazard to the environment. Globally, some 300 million tons of plastic are generated annually, much of it ends up in the soil, oceans, and even the atmosphere. An environmental crisis affecting ecosystem stability, biodiversity, and human health is exacerbated by this pervasive contamination. Plastics break down into micro and nanoplastics, which can enter the human body through contaminated food, water, and air and enter food chains (North and Halden, 2013). Plastics release toxic chemicals including phthalates and bisphenol A (BPA), which interfere with endocrine function and cause problems with metabolism, development and reproduction. Furthermore, plastic particles that settle in agricultural soils have an adverse effect on public health and food security because they lower soil fertility and may introduce hazardous materials into food production. Over 8 million tons of plastic enter the ocean each year, endangering marine life through ingestion, entanglement, and the release of toxic compounds. This makes marine ecosystems especially vulnerable to plastic pollution. In addition to having negative health impacts, fish and marine life that consume

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Table 1: Types of Plastics with their example and common uses

Plastic Type	Example	Common Uses
PET (Polyethylene Terephthalate)	Water bottles, food packaging	Beverage bottles, food containers
HDPE (High Density Polyethylene)	Milk jugs, detergent bottles	Bottles for household products, pipes
PVC (Polyvinyl Chloride)	Pipes, cable insulation	Construction materials, electrical cables
LDPE (Low Density Polyethylene)	Plastic bags, squeeze bottles	Plastic bags, packaging films
PP (Polypropylene)	Food containers, bottle caps	Food containers, packaging, automotive parts
Nylon	Fishing lines, toothbrush bristles	Textile Fibers, toothbrushes, automotive parts
PU (Polyurethane)	Foam cushions, elastomers	Furniture cushions, shoe soles, insulation
PPE (Polyphenylene Ether)	Water-resistant coatings	Electrical connectors, water-resistant applications
EVA(Ethylene Vinyl Acetate)	Foam padding, shoe soles	Sports equipment, shoe insoles

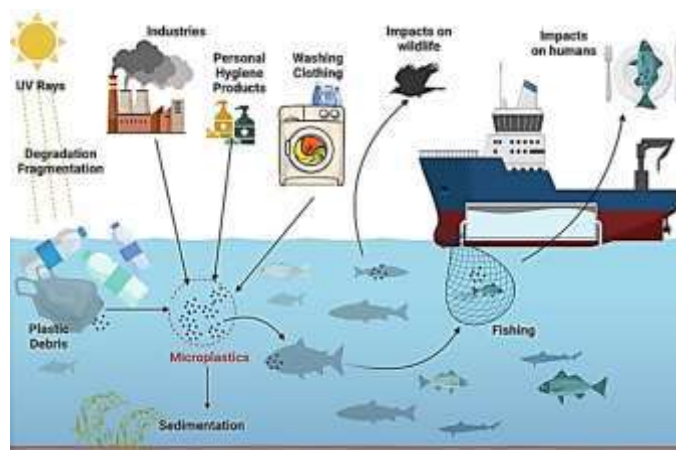
microplastics pose a risk to food safety since these pollutants can go up the food chain and eventually affect human health. Plastic particles in soil have an adverse effect on soil fertility, lower crop yields, and bring pollutants into agriculture, all of which have an influence on public health and food safety. By obstructing drainage systems, aggravating flooding, and raising the danger of vector-borne illnesses, plastic pollution in cities and waterways also presents health risks. The Great Pacific Garbage Patch, which is twice the size of Texas and represents the extent of uncontrolled plastic trash worldwide, is a striking emblem of the urgency of this catastrophe in the Pacific Ocean. Plastic fragments having size smaller than 5 mm are considered as Microplastics (MPs), which can show bioaccumulation and biomagnification potency. MPs are now-a-days ubiquitously present in all the compartments of environment (lithosphere, hydrosphere, and atmosphere). There have been several recent reviews published, which discuss the fate, and occurrence of MPs in natural setting. Due to agricultural intensification and plastic landfilling practices, MPs contamination in terrestrial ecosystems, including agricultural soil, has recently drawn attention. It has been estimated and reported that there are 4-23 times more MPs in

terrestrial environments than in marine environments. In contrast to aquatic ecosystems, terrestrial environments exhibit distinct physico-chemical properties. MPs were found in a variety of concentrations in industrial, agricultural, home garden, coastal, and floodplain soils. The presence of MPs in terrestrial soils exhibits a variety of toxicological and environmental impacts on the soil's flora and fauna (Rillig *et al.*, 2019).

Impacts on ecosystems

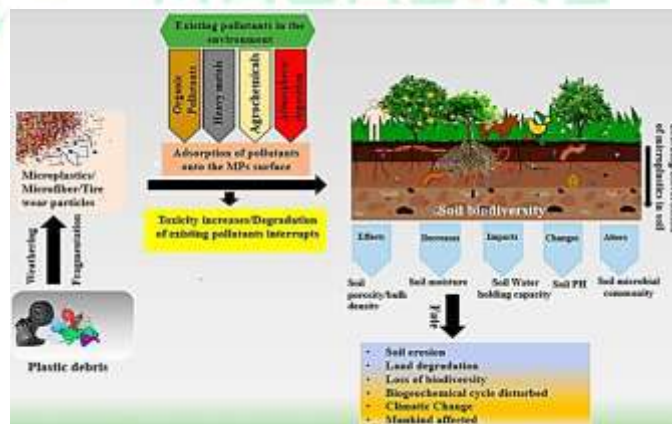
Although it is known that plastics are present in many terrestrial systems, little is known about how they affect ecosystems. It has been demonstrated that terrestrial birds and mammals are harmed by macroplastics, mostly by entanglement. Animals come into contact with macroplastic garbage in a variety of environmental contexts, including isolated areas like desert regions in the United Arab Emirates. It is believed that up to half of camels suffer detrimental effects from ingesting macroplastic. If plastics are ingested in high enough amounts or are big enough to obstruct digestion, they could have negative effects. Because their digestive systems are intricate and prone to obstructions, mammals and birds seem to be impacted in the saltwater environment.

Terrestrial Ecosystems: While a greater amount is dumped in landfills, plastics are typically separated for processes like recycling and waste-to-energy. Microplastics are tiny fragments of plastic produced by processes including UV and microbial degradation. These particles penetrate into the soil and form an impenetrable barrier that prevents the circulation of water and fertilizer. Even more detrimental effects result from the accumulation of these polymers during the rainy season. Tiny plastic particles frequently get up in canals and drainage systems, which eventually go to water bodies and the ocean, as a result of soil erosion or flooding. It has been observed that there are multiple paths involved in the bidirectional movement of micronanoplastics between freshwater bodies (primary sink) and land (dominant source). However, point MNP pollution and diffuse inputs affect these keystone sources and sinks. MNPs are heavily transported to the receiving waterways by runoff from agricultural, urban, recreational, and industrial sites (Bondelind *et al.*, 2019). Because of the downstream storm drainage, which is proof of the runoff channel, MNPs are also found in the Thames River's sediments.



Through flooding and irrigation, the MNPs burden in freshwater bodies may potentially return to the terrestrial ecosystem. WWTP is in charge of moving a significant amount of MNPs from water to soil, as was indicated in the previous section.

Aquatic Ecosystems: Ocean waves abrasive properties, microbes, and ultraviolet light all aid in the breakdown of plastics. Financial losses for small fisheries businesses can result from vessels being damaged by marine debris, which not only raises maintenance costs but also reduces the number of days at sea. The fishing industry has suffered significant losses as a result of unfavorable environmental circumstances, particularly in terms of fewer shellfish caught (Balogun *et al.*, 2019). Currency depreciation, decreased revenue, and expensive upkeep are typically the ways that the effects are most noticeable.



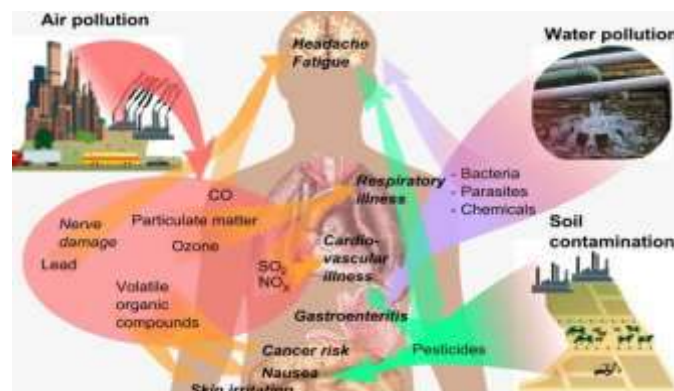
Mangrove Ecosystems: Plastic pollution affects the nitrogen released by seagrass litters, which may have an effect on the nutrient and biogeochemical cycles near the shore. According to Walther and Bergmann (2022), plastic contamination decreased the rate of eelgrass breakdown by 36%. The deep seafloor is a possible sink for this kind of plastic litter because

about half of the plastics from municipal waste are denser than saltwater and sink directly to the bottom. The Sundarbans, the largest mangrove forest in the world, which is located in Bangladesh and India, is seriously threatened by plastic pollution. Plastic garbage that leaks through rivers has made the Sundarbans into a landfill. Microplastics sink more quickly in deep waters because of their higher surface-to-volume ratio, which causes more fouling. This effect is more noticeable when these particles are mixed with feces and aggregates.

Impact on Human Health

Because the catalyst used to make PET is chemically linked into the polymer at very low levels of 200-300 parts per million, long-term liquid storage in PET-based containers causes the leaching of antimony trioxide, a substance thought to be carcinogenic. Trace amounts of antimony may migrate into the liquid content or beverages left in them as a result of prolonged exposure to a heated environment and prolonged liquid storage. Even though the average amount of antimony that leaches into liquids is less than one part per billion, it can still be dangerous to store liquids in PET containers for an extended period of time or to leave them in heated environments like vehicles, garages, or covered storage. Fossil fuels are the source of up to 99% of polymers. A variety of hazardous pollutants, including benzene and volatile organic compounds (VOCs), are released into the air and water in significant quantities as a result of oil and gas mining, particularly hydraulic fracturing for natural

gas. Inhaling and consuming contaminated water and air exposes one to them. They can cause cancer, neuro-reproductive disorders, age-related toxicity, and disruption of the immune system, sensory organs, liver, and kidney (Parker, 2019).



The disruption of human lives by plastics extends beyond environmental bounds. Chemical additives found in plastics, including phthalates, bisphenol A (BPA), and brominated flame retardants (BFRs), have the potential to seriously harm public health (Pawar *et al.*, 2016). Pregnant women's blood, amniotic fluid, placental tissue, and cord blood can all contain BPA, which suggests fetal exposure. Using feeding bottles made of plastic exposes young newborns to BPA often (Kumar, 2018). Human health problems such as cancer, birth defects and developmental disorders, chronic respiratory diseases, cardiovascular disease, and chronic renal disease can all be brought on by bisphenol-A. Oral intake, skin contact, and inhalation are frequently the main ways that humans are exposed to these drugs. Exposure to certain chemical compounds present in plastic materials has been linked to cases of dermatitis. Microplastics are serious contaminants that can build up in the food chain after being consu-

med by a variety of fresh-water and marine animals, potentially endangering human health. Plastics may have detrimental effects on human health through a variety of mechanisms, such as the presence of monomeric building blocks (like bisphenol A), the addition of additives (like plasticizers), or a combination of both (like anti-microbial polycarbonate). Oral intake, skin contact, and inhalation are frequently the main ways that humans are exposed to these drugs. Exposure to certain chemical compounds present in plastic materials has been linked to cases of dermatitis. Microplastics are serious contaminants that can build up in the food chain after being consumed by a variety of freshwater and marine animals, potentially endangering human health (Schneider *et al.*, 2009). Plastics may have detrimental effects on human health through a variety of mechanisms, such as the presence of monomeric building blocks (like bisphenol A), the addition of additives (like plasticizers), or a combination of both (like antimicrobial polycarbonate).

Conclusion

Despite the fact that plastic is a vital part of civilization and has been fundamental to development, plastic trash poses a threat to the environment due to its detrimental effects. Plastics have a favorable impact on our daily lives due to its basic use in household chores and the industrial packaging of various finished goods. Plastics play a number of essential roles in our daily lives due to their physicochemical makeup, but if their post-use

disposal is improperly managed, they may endanger both human health and the environment. Even if plastics have a lot to offer in the future, it is obvious that the way we now make, use, and discard them is unsustainable for wildlife and human health. Periodic plastic clean-up programs need to be strengthened in order to eradicate the current plastic trash in the environment and stop plastic discharge downstream. It is necessary to support robust monitoring and incentive programs for organizations that recycle plastic.

References

- Balogun Ayodeji, T. (2019). Pyrolysis of waste plastics: a case study of polyethylene. *International Journal of Advanced Academic Research Sciences, Technology and Technology*, 5(3): 1-16.
- Kumar, M., Chen, H., Sarsaiya, S., Qin, S., Liu, H., Awasthi, M. K., ... and Taherzadeh, M. J. (2021). Current research trends on micro-and nano-plastics as an emerging threat to global environment a review. *Journal of Hazardous Materials*, 409: 124967.
- North, E. J. and Halden, R. U. (2013). Plastics and environmental health: the road ahead. *Reviews on Environmental Health*, 28(1): 1.
- Parker, L. (2019). The world's plastic pollution crisis explained. *National Geographic*, 7(06): 18.
- Rillig, M. C., Lehmann, A., de Souza Machado, A. A. and Yang, G. (2019). Microplastic effects on plants. *New Phytologist*, 223(3): 1066-1070.

- Pawar, P. R., Shirgaonkar, S. S. and Patil, R. B. (2016). Plastic marine debris: Sources, distribution and impacts on coastal and ocean biodiversity. *PENCIL Publication of Biological Sciences*, 3(1): 40-54.
- Schneider, M., Stracke, F., Hansen, S. and Schaefer, U. F. (2009). Nanoparticles and their interactions with the dermal barrier. *Dermatoendocrinology*, 1(4): 197-206.



Slim Down Naturally: Top Medicinal Plants for Weight Loss

Anita Balakrishna Joshi and Sumanlata Rawat

Introduction

Due to sedentary lifestyles, energy-dense foods and intricate metabolic, genetic and environmental connections, obesity has become one of the most important worldwide health issues of the twenty-first century (Aremu *et al.*, 2025). Obesity is a chronic condition of carbohydrate and fat metabolism that puts human health and well-being at risk. It is defined as abnormal or excessive fat deposition in adipose tissue and other internal organs such the liver, heart, and skeletal muscle. The body mass index (BMI), which is calculated by dividing height (in meters) by weight (in kilograms), is used to measure it. A person can be categorized as underweight, normal, overweight, or obese using their BMI. Overweight people have a BMI of at least 25 kg m^{-2} and obese people have a BMI of at least 30 kg m^{-2} . Diabetes mellitus, heart disease, and cancer are just a few of the chronic illnesses for which being overweight or obese is a significant risk factor. In the past, obesity was seen as a health concern in developed nations, but it is currently widespread, especially in cities. This is caused by a variety of etiologic causes, such as genetic, metabolic, behavioral, and environmental factors. The sharp rise in the frequency of overweight and obesity indicates

that environmental and behavioral factors, rather than biological alterations, are more important. Although conventional pharmacological treatments and lifestyle modifications remain central to obesity management, these approaches often show limited long-term success, undesirable side effects or reduced patient compliance (Chamarthi and Daley, 2025). As a result, natural, plant-based approaches that might provide safer and more sustainable solutions have drawn increasing attention from both the scientific community and the general public. Because they are a rich source of bioactive chemicals with therapeutic potential, medicinal plants have been an essential part of traditional healing systems in many cultures. Many species have characteristics that affect metabolism, hunger, lipid absorption, thermogenesis, and glycaemic regulatory systems that are directly related to controlling body weight. While some lesser-known species, such as *Achyranthes aspera*, *Casearia sylvestris*, *Geranium nepalense*, and *Neolitsea cassia*, are being reexamined for their metabolic benefits, plants like *Camellia sinensis*, *Garcinia gummi-gutta*, *Capsicum annuum* and *Trigonella foenum-graecum*, have gained scientific recognition for their anti-obesity effects. Due to their deep cultural and ethnobotanical

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value, these therapeutic plants are consumed in a variety of ways, from teas and decoctions to functional meals, powders, and extracts. The current study gathered data on a variety of plants that have historically been used to control weight. Recent research attempts to connect traditional knowledge with modern scientific understanding through their botanical identification, families, ways of use, and supporting literature.

Medicinal plants used in weight loss

Vrikshamla (*Garcinia cambogia*): Extracts made from the dried peel of *Garcinia cambogia* fruits. Some herbal appetite suppressants and energy products contain Linn, a member of the Clusiaceae family. (-)-hydroxycitric acid, the active component of *Garcinia cambogia*, inhibits fat production and suppresses hunger to combat obesity. According to studies, this natural extract may also lessen the rate at which extra calories are converted to body fat. Thus it is a highly useful natural remedy for managing cholesterol and obesity. Hydroxycitric acid, or HCA, is a naturally occurring compound that is taken from the peels of *Garcinia cambogia* fruits. HCA effectively inhibits lipogenesis in animal tests, which lowers cholesterol and lipids, enhances the liver's generation of glycogen, suppresses hunger, and boosts the body's thermogenesis process all of which aid in weight loss. Additionally, HCA lowers the pace at which carbs are converted to fats by altering metabolic activity. Additionally, some research suggests that HCA inhibits the action of the liver's ATP citrate lyase enzyme, which converts

carbohydrates to fats (Saito, 2005).

Guggul (*Commiphora mukul*): The Ayurvedic medical system has long employed the resins of the *Commiphora mukul*, a member of the Burseraceae family, to cure obesity. By strengthening the thyroid, boosting the body's ability to burn fat, and enhancing thermogenesis or the generation of heat *Commiphora mukul* improves the body's metabolic activity. It has been demonstrated that extracts containing ketonic steroid active compounds, such as guggulsterones, considerably reduce serum triglycerides and low-density lipoprotein and very low-density lipoprotein (LDL and VDRL, respectively). Moreover, it increases HDL (high-density lipoprotein) cholesterol levels. Research showed a 30% reduction in total cholesterol in 12 weeks, a 35% decrease in LDL, and a 20% increase in HDL in three months (Nityanand and Kapoor, 1971).



Mustak (*Cyperus rotundus*): The term “nut grass” refers to the rhizomes or tubers of *Cyperus rotundus* L., a member of the Cyperaceae family. It was utilized in both its fresh and dry forms in the traditional medicinal system. The active component is cyperine, which has anti-inflammatory, hypoten-

sive (low blood pressure), and diuretic (increased urine output) properties in addition to lowering body fat. It enhances digestive processes, according to Ayurvedic medicine. Changes in digestive system regulation are thought to cause indigestion and block the body's energy-controlling channels, which ultimately results in obesity. *Cyperus rotundus* is particularly helpful against obesity because it helps unclog the blocked channels.

Kutki (*Picrorhiza kurroa*): The *Picrorhiza kurroa* family's root or rhizome. The active component comes from the Scrophulariaceae family. *Picrorhiza kurroa* enhances gallbladder secretions, which helps with fat metabolism and digestion. It works incredibly well to control the liver's fat metabolism. After 12 weeks, daily dosages of *Picrorhiza kurroa* water extract dramatically decreased total cholesterol, triglycerides, and LDL levels in a trial on hyperlipidemic mice fed a high-fat diet (Lee *et al.*, 2006).

Khadir (*Areca catechu*): The Arecaceae family's *Areca catechu* seed lowers the conversion of carbs to fats and preserves a healthy fat metabolism. Additionally, it reduces false hunger and improves exercise outcomes to promote weight loss and reduce excess body fat. Betel nut extracts dramatically reduced triglycerides and cholesterol in rats given a diet containing cholesteryl oleate.

Punarnava (*Boerhavia diffusa*): The entire herb of *Boerhavia diffusa*, family Nyctaginaceae, Punarnava has been used in the traditional medicine since ancient times. It is present in almost all anti-obesity

herbal medicine in one form or another and plays an important role in the treatment of obesity.

Vacha (*Acorus calamus*): *Acorus calamus*, a member of the Araceae family, has roots and rhizomes that can help lower triglycerides and LDL cholesterol while also aiding in weight loss. Alcoholic or aqueous extracts of calamus roots and rhizomes have been shown in animal experiments to lower triglyceride and cholesterol levels while raising HDL levels on an atherogenic diet (Parab and Mengi, 2002). These investigations suggest that calamus may have an antihyperlipidemic effect, although its therapeutic significance is still uncertain.

Green Tea (*Camellia sinensis*): The leaves of *Camellia sinensis*, a member of the Theaceae family, stimulate fat oxidation and induce thermogenesis, increasing the metabolic rate by 4% without raising the heart rate, but they won't cause a quick drop in body weight. Men who took the extract containing epigallocatechin-3-gallate (EGCG) burnt more calories daily than the placebo group, according to a human study on green tea extract. This suggests that the thermogenic effects of green tea extract may be crucial in preventing obesity (Dulloo *et al.*, 1999).

Conclusion

India's obesity problem has made finding efficient Indian natural remedies a top concern. Only a small number of products have undergone comprehensive testing, despite the fact that many Indian and other herbs have been heavily promoted and used for weight loss. It is necessary to raise awareness about the evidence supporting the use of

natural products in the form of raw materials, crude extracts, or isolated compounds to promote weight loss and thereby control obesity, even though there isn't a magic bullet among Indian herbs that can melt kilograms of fat in a short amount of time. Based on sound clinical experience, traditional Indian medicine has great potential for treating obesity.

References

- Aremu, S. O., Akute, B., Aremu, D. O., Zando, C., Aremu, E. D., Nwachukwu, O. J., ... and Aremu, M. O. (2025). Dietary strategies for preventing and managing obesity through evidence-based nutritional interventions. *Discover Public Health*, 22(1): 424.
- Chamarthi, V. S. and Daley, S. F. (2025). Obesity medications: evidence-based management. *StatPearls*.
- Dulloo, A. G., Duret, C., Rohrer, D., Girardier, L., Mensi, N., Fathi, M., ... and Vandermander, J. (1999). Efficacy of a green tea extract rich in catechin polyphenols and caffeine in increasing 24-h energy expenditure and fat oxidation in humans. *The American Journal of Clinical Nutrition*, 70(6): 1040-1045.
- Lee, H. S., Yoo, C. B. and Ku, S. K. (2006). Hypolipemic effect of water extracts of *Picrorrhiza kurroa* in high fat diet treated mouse. *Fitoterapia*, 77(7-8): 579-584.
- Nityanand, S. and Kapoor, N. K. (1971). Hypocholesterolemic effect of Commiphora mukul resin (guggal). *Indian Journal of Experimental Biology*, 9(3): 376-377.
- Parab, R. S. and Mengi, S. A. (2002). Hypolipidemic activity of *Acorus calamus* L. in rats. *Fitoterapia*, 73(6): 451-455.
- Saito, M., Ueno, M., Ogino, S., Kubo, K., Nagata, J. and Takeuchi, M. (2005). High dose of *Garcinia cambogia* is effective in suppressing fat accumulation in developing male Zucker obese rats, but highly toxic to the testis. *Food and Chemical Toxicology*, 43(3): 411-419.

Effectiveness of Farmer FIRST Programme Interventions in Enhancing Income, Employment and Food Security

Mukul Kirar

Introduction

Indian agriculture is increasingly challenged by fragmented landholdings, rising input costs, climate variability, and uncertain markets. These challenges directly affect the income stability, employment availability, and food security of farm households, particularly small and marginal farmers. In response, the extension system in India has gradually shifted from top-down technology transfer to more farmer-centric and participatory approaches. One such initiative that has gained national attention is the Farmer FIRST Programme, which places farmers at the centre of research, extension, and innovation. The Farmer FIRST Programme (FFP) was designed with the core objective of enhancing farmers' livelihoods by addressing location-specific problems through on-farm research, capacity building and continuous extension support. Evidence emerging from field-level evaluations clearly indicates that FFP interventions have had a positive and measurable impact on income, employment generation, and food security among beneficiary farmers.

Farmer FIRST Programme: A Farmer-Centric Extension Model

Unlike conventional extension approaches, the Farmer FIRST Programme emphasizes farmer

participation in technology identification, testing, and refinement. Farmers are not treated merely as recipients of information but as partners in the research-extension continuum. Through on-farm trials, demonstrations, training programmes, and regular interaction with scientists and extension personnel, FFP ensures that technologies are locally relevant and practically feasible. Data from programme implementation areas show that a majority of beneficiary farmers were exposed to multiple extension interventions, including training programmes, exposure visits, diagnostic field visits, and demonstrations. This sustained engagement forms the foundation for improved adoption of Integrated Farming Systems (IFS) and allied technologies.

Impact on Farm Income

One of the most significant outcomes of the Farmer FIRST Programme is its contribution to enhancing and stabilizing farm income. Comparative assessments between FFP beneficiaries and non-beneficiaries consistently reveal higher income levels among beneficiaries. Field data indicate that beneficiary farmers experienced an increase of 15-30 per cent in annual farm income after programme intervention, whereas non-beneficiaries showed only marginal improvement during the same period.

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This income enhancement is largely attributed to the adoption of diversified enterprise combinations under IFS, such as crop-livestock integration, backyard poultry, vegetable cultivation, and value-added activities. Income from allied enterprises alone contributes 25-40 per cent of total household income among FFP beneficiaries, reducing their dependence on a single crop source.

Employment Generation and Reduction of Seasonal Unemployment

Seasonal unemployment is a persistent problem in mono-cropping systems, often leading to distress migration. Farmer FIRST Programme interventions have demonstrated considerable success in addressing this issue through enterprise diversification and on-farm activity intensification. Data from beneficiary households show that adoption of IFS practices under FFP generated 30-60 additional employment days per year compared to non-beneficiary households. Livestock management, fodder cultivation, compost preparation, poultry rearing, and vegetable production created year-round engagement for family labour. Importantly, these employment opportunities were not limited to male members. Women and elderly family members were actively involved in allied enterprises, resulting in better utilization of family labour and reduced migration during lean agricultural seasons.

Improvement in Food and Nutritional Security

Food security is a crucial dimension of livelihood security, and Farmer FIRST Programme interventions have shown a clear positive influence

in this area. Beneficiary households adopting IFS reported higher availability and diversity of food items, including milk, vegetables, eggs, and pulses. Survey data indicate that a substantial proportion of FFP beneficiaries achieved year-round availability of vegetables and milk from their own farms. Kitchen gardening and livestock components alone were found to meet 30-50 per cent of household nutritional requirements, significantly reducing dependence on market purchases. In contrast, non-beneficiary households often relied heavily on purchased food and exhibited lower dietary diversity, particularly during off-season periods.

Adoption of Integrated Farming Systems under FFP

The Farmer FIRST Programme has been instrumental in promoting Integrated Farming Systems by providing hands-on experience and continuous technical guidance. Adoption data reveal that a majority of FFP beneficiaries adopted two or more IFS components, while non-beneficiaries largely remained confined to crop-based systems. Adoption intensity among beneficiaries was found to be significantly higher, with a greater proportion falling under medium to high adoption categories. This demonstrates that participatory extension approaches are more effective than conventional advisory methods in promoting system-based technologies like IFS.

Role of Extension Contact and Capacity Building

Extension contact is a cornerstone of the Farmer FIRST Programme. Beneficiary farmers

reported frequent interaction with scientists and extension personnel, which enhanced their confidence and problem-solving ability. Data show that farmers with higher extension contact scores recorded significantly better adoption and livelihood outcomes. Capacity-building activities such as training programmes, demonstrations, and exposure visits played a critical role in strengthening farmers' technical skills. Farmers exposed to repeated training interventions showed lower knowledge-adoption gaps compared to those with limited exposure.

Behavioral and Social Outcomes

Beyond economic benefits, FFP interventions have also influenced farmers' behavioral and social dimensions. Beneficiary farmers exhibited higher levels of scientific orientation and risk-taking ability, enabling them to experiment with diversified enterprises. Social participation also improved, as farmers became more involved in farmer groups, training programmes and community-level activities. This enhanced social capital further facilitated information exchange and collective learning within villages.

Gender Dimensions of FFP Interventions

Gender-disaggregated data highlight the inclusive nature of the Farmer FIRST Programme. Women in beneficiary households actively participated in livestock rearing, poultry management, kitchen gardening, and value addition activities. Their involvement contributed significantly to household income and food security. In many cases, women's participation in decision-making related to

enterprise management increased by 15-25 per cent after programme intervention, indicating a positive shift toward gender empowerment.

Constraints and Lessons Learned

Despite its success, the Farmer FIRST Programme faces certain constraints. Limited coverage, resource constraints, and the need for continuous follow-up remain challenges. Some farmers also reported difficulties in accessing credit and inputs during the initial adoption phase. However, programme evaluations clearly indicate that farmer-centric planning, participatory research, and sustained extension support are key strengths that should be retained and expanded.

Way Forward

The positive outcomes of the Farmer FIRST Programme provide valuable lessons for future extension strategies. Scaling up such interventions requires:

- ✓ Strengthening farmer–scientist interaction
- ✓ Promoting enterprise-based diversification
- ✓ Ensuring timely input and credit support
- ✓ Integrating digital advisory services with field extension

Data-driven monitoring and feedback mechanisms can further enhance programme effectiveness.

Conclusion

The Farmer FIRST Programme has demonstrated its effectiveness in enhancing income, generating employment, and improving food security among farming households. By placing farmers at the centre of research and extension

activities, the programme has successfully promoted Integrated Farming Systems and strengthened livelihood security. Empirical evidence clearly suggests that farmer-centric, participatory extension approaches like FFP hold immense potential for building resilient, inclusive, and sustainable agricultural livelihoods in India.



Cyclaniliprole: A Novel Diamide Insecticide - A Comprehensive Review

Hirapara Avani and P. B. Patel

Introduction

Insect pests are a major constraint in agricultural production, causing significant yield losses in food and commercial crops. Insecticides are an essential component of modern agriculture, playing a crucial role in ensuring global food security and protecting crops from devastating pests. In the absence of crop protection measures, the yield of most crops fall by 50-90 per cent. The pesticides production in India started in 1952 and currently India occupies 4th position in agrochemicals production. Although integrated pest management (IPM) emphasizes the judicious use of pesticides, chemical insecticides continue to play a vital role in modern agriculture. Continuous use of conventional insecticides has resulted in resistance development, resurgence of pests and environmental concerns, necessitating the introduction of novel molecules with new modes of action. Cyclaniliprole is one such recently developed new-generation insecticide that fits well into resistance management and IPM programmes.

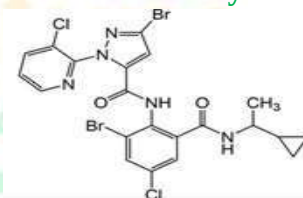
Global and Indian History of Cyclaniliprole

Cyclaniliprole was developed by Ishihara Sangyo Kaisha Ltd. as a member of the diamide class of insecticides. Globally, it was first registered in

countries such as Japan, Korea, the United States and Canada during 2017. The molecule is classified under IRAC Group 28 due to its action on ryanodine receptors. In India, cyclaniliprole was first registered by ISK Biosciences India Pvt. Ltd. Under the Central Insecticides Board and Registration Committee (CIB&RC) on 22 December 2022 in the formulation Cyclaniliprole 100 DC. Subsequently, Cyclaniliprole 8.0 SL was approved on 17 October 2023. At present, cyclaniliprole is registered in India for the management of stem borer and leaf folder in rice only.

Chemistry and Chemical structure of cyclaniliprole

Cyclaniliprole is a diamide insecticide with the molecular formula



Chemical Structure

$C_{21}H_{17}Br_2Cl_2N_5O_5$. Its systematic chemical name is 2',3-dibromo-4'-chloro-1-(3-chloro-2-pyridyl)-6'-{[(1RS)-1-cyclopropylethyl] carbamoyl}pyrazole-5-carboxanilide. The molecule contains a pyrazole carboxamide structure, which is responsible for its high biological activity. Cyclaniliprole is effective at very low application rates compared to older insecticide classes.

Physical & Chemical Properties of cyclaniliprole

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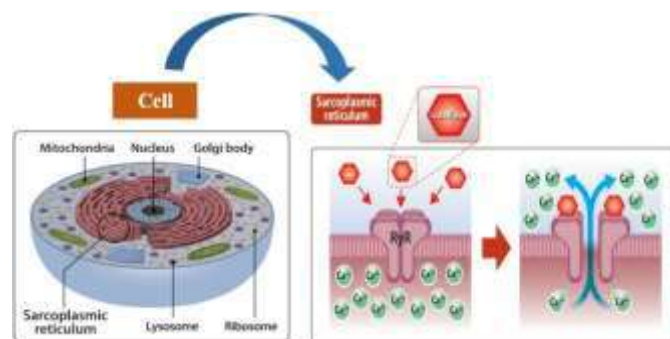
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- ✓ Physical form: white powder
- ✓ Molecular weight: 602.1 g mol⁻¹
- ✓ Melting point (°C): 241- 244°C
- ✓ Density: 1.6 g cm⁻³ at 20 °C.
- ✓ Solubility: Very low in water (0.15 mg L⁻¹ at 20°C); moderately soluble in solvents like acetone, methanol
- ✓ pH Stability: Stable in pH 4 to 9 range.

Mode of Action

The target site of Cyclaniliprole is the Ryanodine Receptor, or RyR. This Ryanodine receptor is a calcium-release channel located on the membrane of the sarcoplasmic reticulum in the muscle cell of insect. Under normal conditions, the RyR carefully controls the release of calcium ions, allowing muscles to contract and then relax properly. First, Cyclaniliprole enters the insect's body either through ingestion - when the larvae feed on treated leaves or through direct contact with the insect cuticle. After entering into the insect's body, it is carried through the hemolymph and reaches the muscle cells. Inside the muscle cell, Cyclaniliprole binds to a specific site on the Ryanodine receptor. This binding causes activation of the Ryanodine receptor. This leads to continuous and uncontrolled release of calcium ions from the sarcoplasmic reticulum into the cytoplasm. Normally, calcium release is tightly regulated, but due to Cyclaniliprole, the channel remains continuously open. This causes a sudden flood of calcium within the muscle cell. The excess calcium leads to sustained muscle contraction, which results in muscular paralysis. Because of

this, the insect stops feeding and eventually dies due to exhaustion and energy depletion.



Bio-efficacy Against Insect Pests

Extensive studies have demonstrated the broad-spectrum efficacy of cyclaniliprole against several insect orders.

Lepidoptera: Cyclaniliprole shows excellent control of major lepidopteran pests such as *Helicoverpa armigera*, *Spodoptera litura*, soybean semilooper, diamondback moth. It is effective against different life stages and provides long-lasting protection with rapid feeding inhibition.

Hemiptera: The insecticide has shown moderate to good activity against hemipteran pests such as aphids, whiteflies and bugs. Sub-lethal exposure has been reported to reduce adult longevity and fecundity, contributing to population suppression.

Coleoptera: Cyclaniliprole is effective against beetle pests including Colorado potato beetle, Plum curculio, Japanese beetle, flea beetle and Mexican bean beetle. Significant reduction in larval and adult populations has been reported under field conditions.

Diptera: Studies indicate that cyclaniliprole effectively controls dipteran pests such as cabbage maggot by reducing larval damage and root infestation.

Thysanoptera: Good efficacy has been reported

against thrips in crops such as strawberry and citrus, where cyclaniliprole performed comparably or superior to existing insecticides.

Effect on Natural Enemies

Research findings suggest that cyclaniliprole is relatively safe to many beneficial arthropods when applied at recommended doses. This selectivity enhances its compatibility with IPM programmes.

Residues and Maximum Residue Limits

Cyclaniliprole residues dissipate gradually and remain within permissible limits when used as per label recommendations. Maximum residue limits (MRLs) for cyclaniliprole in various crops range from 0.01 to 3.0 ppm, indicating its suitability for safe food production.

Toxicological Profile

Cyclaniliprole exhibits low mammalian toxicity. It is slightly irritating to the eyes but is not a skin sensitizer. Long-term studies have shown no evidence of carcinogenicity, mutagenicity or reproductive toxicity. No specific antidote is available, and treatment in case of exposure is symptomatic.

Role in Integrated Pest Management

Due to its novel mode of action, high efficacy at low doses and safety to non-target organisms, cyclaniliprole is well suited for inclusion in IPM and resistance management strategies. Rotation with insecticides having different modes of action is recommended to delay resistance development.

Conclusion

Cyclaniliprole represents a novel addition to

the diamide class of insecticides belongs to IRAC 28 Group, developed by Ishihara Sangyo Kaisha Ltd. It acts on the ryanodine receptor of insect muscles, leading to rapid feeding cessation, muscle contraction, paralysis and death. Cyclaniliprole exhibits excellent control against a wide range of lepidopteran, hemipteran, dipteran and coleopteran pests. It provides long-lasting protection even at low doses and is highly selective to target pests, showing minimal effects on mammals and beneficial organisms. In India registration for Cyclaniliprole 10% w/v DC and Cyclaniliprole 8.0 SL from CIBRC has been done for management of stem borer and leaf folder in rice only. Its toxicological profile reveals no carcinogenic, mutagenic or reproductive toxicity concerns. MRLs of Cyclaniliprole for different crops/edibles is in ranges from 0.01 to 3 ppm. Its unique mode of action, broad-spectrum efficacy, long residual activity and favourable toxicological profile make it a promising molecule for sustainable insect pest management. Although currently registered for limited use in India, cyclaniliprole has strong potential for future label expansion in diverse crops.

References

- Li, X., Zhang, X., Zhang, W., Song, C., Wang, F., Qin, R., Zhu, G., Wang, G., Yu, J. and Wang, H. (2025). Sublethal and Transgenerational Effects of Cyclaniliprole on Demographic Parameters in *Rhopalosiphum padi* and *Schizaphis graminum* (Hemiptera: Aphididae). *Insects*, 16(9): 882.

- Bala, S. (2020). Population fluctuation and management of gram pod borer, *Helicoverpa armigera* (Hubner) infesting chickpea in new alluvial zone of West Bengal, India. *Journal of Entomology and Zoology Studies*, 8(1): 262-266.
- Channakeshava, R., Somanagouda, G., Huilgol, S. N., Naidu, G. and Banu, H. (2022). Efficacy of Cyclaniliprole 100 DC for the management of major defoliators in Soybean. *Journal of Oilseeds Research*, 40: 119 -121.
- DiMeglio, A. S., Aigner Jr, J. D., Wilson, J. M., Nottingham, L. B., Morehead, J. A. and Kuhar, T. P. (2015). Field Efficacy of IKI 3106 50SL for the Control of Harlequin Bugs in Collards in Virginia, 2014. *Arthropod Management Tests*, 40(1): 4.
- Guédot, C. and Perry, R. S. (2016). Evaluation of Early Season Foliar Applications of Insecticides for the Control of Flea Beetle in Cranberry, 2015. *Arthropod Management Tests*, 41(1): 113.
- Prasanna, P. M., Badiger, B. and Shivamurthy, D. (2020). Bio-efficacy of insecticide, Cyclaniliprole 100 DC against gram pod borer, *Helicoverpa armigera* Hubmer. Infesting chickpea. *International Journal of Chemical Studies*, 28(4): 3070-3073.
- Walgenbach, J. F. and Schoof, S. C. (2017). Evaluation of Cyclaniliprole for Control of Plum Curculio on Apples, 2015. *Arthropod Management Tests*, 42(1): 53.
- Nottingham, L. B., Aigner, J. D., Wilson, J. M., Morehead, J. A., DiMeglio, A. and Kuhar, T. P. (2015). Laboratory Bioassay Evaluation of IKI-3106 (Cyclaniliprole) for Control of Mexican bean beetle and Japanese Beetle, 2014. *Arthropod Management Tests*, 40(1): 07.
- Sances, F. V., Flora, E., Spence, A., LeBlanc, M. L., Grove, M. and Whipple, S. D. (2014). Cabbage Maggot Control with IKI-3106 (Cyclaniliprole), 2012. *Arthropod Management Tests*, 39(1): 55.

Advanced Geostatistical Approaches for Spatial Mapping of Soil Properties

Ankit Singh, Pardeep Phogat, Yogesh Rajrana and Krisanu Golui

Abstract

Spatial mapping of soil properties plays a crucial role in precision agriculture, land management and environmental sustainability. The accurate prediction and mapping of soil attributes such as texture, organic matter content, nutrient levels and pH are essential for improving agricultural productivity and maintaining soil health. Geostatistical techniques provide a robust framework for analyzing and predicting the spatial variability of soil properties. The performance of Inverse Distance Weighting (IDW), Ordinary Kriging (OK), and Universal Kriging (UK), individually and in combination with Principal Component Analysis (PCA) and Fuzzy Clustering Algorithm (FCA), is assessed for the development of high-resolution soil property maps. IDW relies on the assumption that nearby samples have greater influence on unsampled locations, while OK and UK employ semivariogram models to quantify spatial correlation, with UK further accounting for external trends. PCA reduces the dimensionality of soil data and enhances the identification of dominant patterns, whereas FCA classifies soil properties into clusters based on similarity measures. The comparative analysis of these methods highlights the strengths and limitations of each approach, emphasizing the importance of selecting appropriate geostatistical and machine learning techniques to improve the accuracy and reliability of soil property mapping. The findings underscore the potential of integrating multiple geostatistical approaches to enhance the spatial resolution and predictive accuracy of soil maps, thereby facilitating informed decision-making in agricultural management and environmental planning.

Introduction

Soil is one of the most critical components of the terrestrial ecosystem, supporting life by serving as the foundation for agricultural production, regulating hydrological and nutrient cycles and acting as a medium for plant growth and biological activity. Its capacity to perform these essential ecosystem functions is determined by its inherent

physical, chemical and biological properties, such as texture, organic matter content, pH, nutrient status, bulk density and microbial populations (Rezaee *et al.*, 2023). However, these properties are not uniform across space; instead, they exhibit significant spatial variability due to complex interactions among natural and anthropogenic factors. Accurately characterizing this spatial variability is crucial for

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enhancing agricultural productivity, implementing sustainable land-use practices and developing effective soil and water conservation strategies (Verma *et al.*, 2021). The variability of soil properties arises from multiple interdependent processes and influences. Natural factors such as parent material, climate, topography and vegetation type plays a fundamental role in shaping soil characteristics. For example, soils derived from different parent materials can have contrasting mineral compositions, drainage properties and fertility levels. Climate influences soil formation processes such as leaching, organic matter decomposition and horizon development, while topographic position affects moisture retention and erosion-deposition dynamics. Anthropogenic activities, including tillage, fertilization, irrigation, deforestation and land use change, further compound soil variability by altering natural soil-forming processes. These factors act at multiple spatial and temporal scales, resulting in heterogeneity that may be observed at the field, landscape or regional level (Shukla *et al.*, 2025).

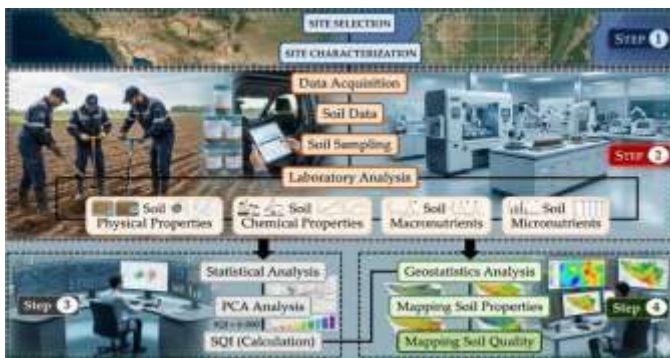


Fig. 1: Flowchart representing the workflow for geostatistical mapping of soil properties

Traditional soil survey and mapping methods

rely heavily on manual sampling and laboratory analysis. These approaches are considered reliable and provide accurate estimates of soil parameters. However, they are inherently labour-intensive, time-consuming and costly, especially when implemented over large and spatially diverse areas. Additionally, due to practical constraints, traditional surveys often result in sparse sampling networks that may miss significant fine-scale spatial patterns. Consequently, such methods are limited in their ability to provide the high-resolution spatial information needed for site-specific soil management a cornerstone of precision agriculture and sustainable land use (Behera *et al.*, 2025). In response to the limitations of conventional methods, the application of geostatistical techniques has gained significant momentum in soil science over recent decades. Geostatistics refers to a suite of spatial analytical tools that enable the quantification and modelling of spatial autocorrelation the tendency of nearby observations to be more similar than distant ones. By capturing this spatial dependence, geostatistical models allow for the estimation of soil properties at unsampled locations, thereby generating continuous soil property maps from discrete point observations (Shukla *et al.*, 2025). Among the most commonly used geostatistical methods is Inverse Distance Weighting (IDW). IDW operates on the intuitive principle that points closer to a target location are more similar and should have a greater influence on the estimated value. It is relatively straightforward to implement, computationally efficient and requires

minimal statistical assumptions. However, its simplicity is also its limitation (Sheng *et al.*, 2021). IDW assumes isotropy uniform spatial structure in all directions and does not account for underlying spatial autocorrelation beyond distance decay. In areas with irregular sampling patterns or clustered observations, IDW can produce oversmoothed or biased estimates, making it less suitable for heterogeneous landscapes (AbdelRehman *et al.*, 2020). To overcome these shortcomings, more advanced geostatistical methods such as Ordinary Kriging (OK) and Universal Kriging (UK) are employed. These methods extend beyond distance-based weighting by incorporating the semivariogram, a statistical function that quantifies the degree of spatial dependence as a function of distance and direction. OK assumes that the variable of interest has a constant mean across the study area and uses both spatial correlation and distance to interpolate values (Farooq *et al.*, 2022). UK builds upon OK by accounting for external trends or covariates such as slope, elevation or land cover that influence soil variability. This makes UK particularly effective in modelling spatial patterns in complex and heterogeneous terrains, where spatial variation arises from both intrinsic and extrinsic factors. Overall, kriging methods tend to outperform IDW in terms of prediction accuracy and map reliability due to their robust statistical foundations (Dash *et al.*, 2024).

While geostatistical interpolation addresses spatial prediction, it does not directly handle the high dimensionality and multicollinearity often present in

soil datasets, where numerous interrelated variables must be analyzed simultaneously. This is where multivariate statistical techniques such as Principal Component Analysis (PCA) become valuable. PCA is a dimensionality reduction tool that transforms correlated variables into a smaller set of uncorrelated principal components (Singh *et al.*, 2026). These components retain the most significant variance in the data, allowing researchers to identify dominant patterns and underlying structures that may not be immediately apparent. By simplifying the dataset without significant information loss, PCA enhances the interpretability of complex soil data and improves the performance of spatial interpolation models (Verma *et al.*, 2021). Complementing PCA, Fuzzy Clustering Algorithm (FCA) offers a powerful means of classifying soil samples based on their similarity across multiple variables. Unlike hard clustering methods that assign each data point to a single cluster, FCA permits partial membership, allowing a soil sample to belong to multiple clusters with varying degrees of association. This soft classification is particularly well-suited for natural systems where transitions between soil types are gradual rather than abrupt. FCA is effective in identifying zones of homogeneous soil properties, which is critical for delineating management zones in precision agriculture and land resource planning. Moreover, when integrated with geostatistical methods, FCA can refine spatial predictions by distinguishing areas with subtle differences in soil characteristics (Tripathi *et al.*, 2024).

The integration of geostatistical and machine learning approaches represents a significant advancement in soil spatial analysis. By combining the predictive power of kriging with the pattern recognition and simplification capabilities of PCA and FCA, researchers can develop comprehensive and high-resolution soil property maps that are both statistically sound and practically useful (Singh *et al.*, 2026). These integrated models provide insights into the spatial structure of soil variability, enhance the accuracy of predictions and facilitate the development of site-specific land management practices that improve resource efficiency, increase crop productivity and reduce environmental impact (Shukla *et al.*, 2025). Despite their advantages, the performance of geostatistical and machine learning techniques is not uniform and can vary depending on the landscape characteristics, data quality and sampling density. Therefore, it is essential to evaluate these methods systematically in different contexts to determine their suitability and effectiveness. High-quality soil information generated through these advanced techniques will play a pivotal role in supporting precision agriculture, informing policy decisions and guiding sustainable development initiatives globally (Srinivasan *et al.*, 2022).

Conclusion

Accurate spatial mapping of soil properties is essential for precision agriculture, soil conservation and sustainable land management. Geostatistical methods such as IDW, OK and UK, alongside

dimensionality reduction and clustering techniques like PCA and FCA, provide a robust framework for capturing and predicting the spatial variability of soil attributes. IDW offers a simple and computationally efficient approach, but is limited by its inability to account for spatial correlation, which can lead to oversimplified predictions. Kriging methods, particularly UK, improve predictive accuracy by incorporating both spatial autocorrelation and external trends, making them well-suited for complex and heterogeneous landscapes. PCA enhances the interpretability of soil data by reducing dimensionality and isolating dominant patterns, thereby improving the predictive performance of geostatistical models. FCA further refines soil mapping by identifying clusters and transitional zones, which improves the resolution and accuracy of spatial predictions. The integration of PCA and FCA with kriging methods provides a powerful framework for generating high-resolution soil property maps that accurately reflect the underlying spatial structure of soil variability. The comparative analysis underscores the importance of selecting appropriate geostatistical and machine learning techniques based on the specific characteristics of the study area and the nature of the soil data. A hybrid approach that combines kriging with PCA and FCA emerged as the most effective strategy for improving the resolution and accuracy of soil property maps. These methods help in advancing soil mapping capabilities, supporting informed decision-making in agricultural planning and promoting sustainable land

management practices. By improving the precision and resolution of soil property maps, these techniques contribute to more efficient use of agricultural inputs, enhanced soil fertility and long-term environmental sustainability.

References

- Behera, S. K., Shukla, A. K., Kumar, R., Mishra, R., Shukla, V., Yadav, H. and Datta, S. P. (2025). Geostatistics-based understanding of temporal changes in spatial distribution of soil fertility parameters in an intensively cultivated area of North India. *Journal of Soil Science and Plant Nutrition*, 25(1): 1-19.
- Dash, P. K., Miller, B. A., Panigrahi, N. and Mishra, A. (2024). Exploring the effect of sampling density on spatial prediction with spatial interpolation of multiple soil nutrients at a regional scale. *Land*, 13(10): 1-25.
- Farooq, I., Bangroo, S. A., Bashir, O., Shah, T. I., Malik, A. A., Iqbal, A. M. and Biswas, A. (2022). Comparison of random forest and kriging models for soil organic carbon mapping in the Himalayan Region of Kashmir. *Land*, 11(12): 1-15.
- Singh, A., Yadav, N., Tomar, D., Golui, K., Phogat, P., Acharya, S., Dahiya, Y., ... and Arya, S. (2026). Geostatistical Characterization, Multivariate Analysis & Zonal Delineation of Fertility Attributes of Soils under Organic Cultivation: A Case Study from a Semi-Arid Agroecosystem of Hisar, Haryana. *Egyptian Journal of Soil Science*, 66(1): 1-24.
- Rezaee, L., Davatgar, N., Moosavi, A. A. and Sepaskhah, A. R. (2023). Implications of spatial variability of soil physical attributes in delineating site-specific irrigation management zones for rice crop. *Journal of Soil Science and Plant Nutrition*, 23(4): 6596-6611.
- Sheng, J., Yu, P., Zhang, H. and Wang, Z. (2021). Spatial variability of soil Cd content based on IDW and RBF in Fujian River, Mianyang, China. *Journal of Soils and Sediments*, 21: 419-429.
- Shukla, A. K., Behera, S. K., Kumar, P., Mishra, R., Shukla, V., Pachauri, S. P. and Datta, S. P. (2025). Delineation of management zones for site-specific soil nutrient management for sustainable crop production. *Land Degradation & Development*, 36: 231-248.
- Srinivasan, R., Shashikumar, B. N. and Singh, S. K. (2022). Mapping of soil nutrient variability and delineating site-specific management zones using fuzzy clustering analysis in eastern coastal region, India. *Journal of the Indian Society of Remote Sensing*, 50(3): 533-547.
- Tripathi, R., Tripathy, B. R., Gouda, A. K., Swain, C. K., Mohanty, S. and Nayak, A. K. (2024). Delineating homogeneous management zones for nutrient management in rice cultivated area of Eastern India. *Journal of Soil Science and Plant Nutrition*, 24(4): 8331-8342.

Insect Biomimetics: From Evolution to Innovation

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Abstract

Insect biomimetics explores the adaptation of insect structures and functions to develop innovative and sustainable technologies. Insects exhibit highly efficient evolutionary traits such as lightweight yet strong body architecture, energy-efficient locomotion, advanced sensory systems and specialized surface properties. These characteristics have inspired applications in medicine, robotics, agriculture, architecture and material science. By translating biological principles into engineering solutions, insect-inspired technologies promote energy efficiency, environmental sustainability and improved performance, offering practical solutions to modern challenges related to resource conservation and technological advancement.

Introduction

Nature has always been the greatest teacher, quietly perfecting its designs over millions of years. Among all living creatures, insects stand out as tiny engineers with extraordinary abilities. Though small in size, they display remarkable strength, efficiency, and adaptability that often surpass human-made systems. From the perfectly shaped honeycomb built by bees to the cooling systems of termite mounds and the painless bite of a mosquito, insects demonstrate solutions to complex problems in the most efficient way possible. Scientists and engineers are now turning to these natural models for inspiration through a field known as biomimetics, or biomimicry. This approach studies how insects function and applies those principles to develop innovative technologies. Insect-inspired ideas have led to lightweight building materials, advanced medical needles, water-harvesting systems, self-cleaning

surfaces, and even flying robots. By observing how insects fly, collect water, stick to surfaces, or see the world through compound eyes, researchers are designing smarter and more sustainable technologies. In a world facing challenges like climate change, water scarcity, and energy demands, learning from insects offers practical and eco-friendly solutions.

Concept of Biomimetic

Biomimetic can also be called as biomimicry. The word “Biomimetics” was coined by Otto Herbert Schmitt in 1957. The word comes from the Greek terms *bios* (life) and *mimesis* (imitation), meaning “to imitate life.” Biomimetics is an interdisciplinary scientific approach that studies the structures, functions, and principles of biological systems and applies them to the design and development of innovative materials, technologies and engineering solutions to address human challenges (Nair *et al.*,

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2024). Rather than directly copying nature, biomimetics focuses on understanding how natural designs work and adapting those ideas for practical use. Since organisms have evolved over millions of years to become efficient and sustainable, their strategies often provide smart, energy-saving, and eco-friendly solutions. In simple terms, biomimetics is innovation inspired by nature.

Why Insects for Biomimetic?

Due to various criteria insects are used as an example for biomimetic or biomimicry in various fields such as robotics, architecture, medicine and material and surface science (Gorb, 2011). Some of the conditions are as follows:

- ✓ Insects show remarkable evolutionary success due to diverse survival mechanisms and highly specialized structural adaptations developed through natural selection.
- ✓ Their lightweight chitin-protein body with hierarchical organization provides high structural efficiency, strength-to-weight ratio, and serves as an excellent model for biomimetic material design.
- ✓ Insects exhibit energy-efficient locomotion such as aerodynamically effective flapping flight and low-energy movement, which inspires micro-robotic and miniature engineering systems.
- ✓ They possess advanced sensory organs and decentralized neural control systems that function efficiently with minimal neural resources, offering models for compact sensors and autonomous technologies.
- ✓ Specialized cuticular surface properties and adaptive physiological mechanisms enable insects to survive extreme environments while inspiring innovations in surface engineering and stress-tolerant materials.

Insects Inspired Biomimetic

Mosquito-Inspired Needle: The mosquito proboscis has evolved as an extremely efficient piercing organ capable of penetrating human skin with minimal pain and tissue damage. Based on this mechanism, bioinspired needles were developed with modified tip geometry and vibration-assisted motion. These needles significantly reduce insertion force and deviation during penetration compared to conventional needles. Such mosquito-inspired designs improve targeting accuracy and minimize patient discomfort, making them highly useful in painless injections, drug delivery systems, microsurgeries and minimally invasive medical procedures (Gidde and Hutapea, 2020).



Bee-Stinger Inspired Surgical Needle: Honeybee stingers possess backward-facing barbs that allow efficient penetration and anchorage within tissues. Mimicking this natural design, researchers developed surgical needles incorporating micro-barbed structures similar to bee stingers. These bioinspired needles reduce friction between tissue and needle surface, thereby lowering insertion force and minimizing tissue deformation. Experimental studies demonstrated improved control over needle

movement and reduced deviation during surgical operations. This innovation enhances precision in medical treatments such as biopsy sampling, targeted drug injection and delicate surgical interventions where accuracy and reduced tissue damage are essential (Hutapea and Sahlabadi, 2018).

Honeycomb-Inspired Composite Structures:

Honeybees construct honeycombs using hexagonal cells that provide maximum strength while using minimum material. This naturally optimized architecture inspired engineers to develop honeycomb sandwich composite materials characterized by lightweight structure, high stiffness and excellent load-bearing capacity. These composites consist of a honeycomb core placed between thin panels, resulting in superior mechanical strength and energy absorption. Due to properties such as thermal insulation, fire resistance and durability, honeycomb-inspired materials are widely used in aircraft construction, automobile components, railway coaches, shipbuilding and aerospace engineering.



Insect-Inspired Adhesive Patch: Many insects possess specialized attachment devices that allow them to adhere to smooth, rough, wet or dry surfaces. Inspired by the adhesive structures present on the forelegs of diving beetles, scientists developed bioadhesive patches capable of strong multidirectional adhesion. These patches utilize microcavities and wrinkle-like surface structures that combine suction and capillary forces to maintain attachment

even under moist conditions. Such insect-inspired adhesive systems are particularly useful in biomedical applications, including electrocardiogram (ECG) monitoring devices, wearable sensors and skin-mounted medical instruments.

Insect Cuticle Inspired Composite Bioplastics:

The insect cuticle is a natural composite material composed mainly of chitin fibers embedded in a protein matrix, providing exceptional toughness, flexibility and protection. Inspired by this biological structure, researchers developed composite bioplastics incorporating chitosan and structural proteins similar to insect cuticular components. These biomimetic materials exhibit enhanced strength, elasticity and stretch-strengthening behavior compared to conventional plastics. Additionally, they are sustainable and biodegradable, making them suitable for applications in medical implants, bioengineering materials and environmentally friendly packaging industries.

Butterfly Wing Inspired Structural Colour Technology:

Many butterflies exhibit brilliant coloration not due to pigments but because of nanoscale surface structures that manipulate light through interference and reflection. Mimicking these structural color mechanisms, scientists developed paints and coatings that produce color without dyes or chemical pigments. These biomimetic coatings reduce toxic chemicals such as volatile organic compounds and eliminate harmful additives used in conventional paints. Applications extend to cosmetics, electronics, packaging materials and environ-

mentally sustainable coating industries, demonstrating how insect photonic structures can revolutionize material science.

Dung Beetle Inspired Mould Board Plough:

Soil-burrowing insects like dung beetles possess non-smooth body surfaces containing convex and concave structures that reduce soil adhesion and friction. Engineers applied this concept to agricultural machinery by designing mould board ploughs with biomimetic surface patterns. These modified plough surfaces significantly decrease sliding resistance and prevent soil sticking during tillage operations. As a result, energy consumption during ploughing is reduced, improving agricultural efficiency and machinery performance.



Desert Beetle Inspired Dew Harvesting System:

Desert beetles living in arid regions collect water from fog using specialized body surfaces composed of hydrophilic spots surrounded by hydrophobic regions. Water droplets condense on hydrophilic areas and roll toward the mouth due to gravity. This natural water collection mechanism inspired artificial fog-harvesting systems capable of collecting atmospheric moisture efficiently. Such biomimetic devices are especially valuable in drought-prone and desert regions for sustainable water harvesting and supply systems.



Conclusion

Insect-inspired biomimetics highlights how

evolutionary adaptations of insects provide efficient solutions for modern technological challenges. The lightweight structures, energy-efficient movement, advanced sensory systems, and specialized surface properties of insects have inspired innovations in medicine, materials science, robotics, agriculture, and engineering. These biological models contribute to the development of sustainable, high-performance, and eco-friendly technologies such as micro-robots, smart sensors, lightweight materials, and water-harvesting systems. By integrating natural design principles with modern engineering, insect biomimetics offers promising approaches for future technological advancement and sustainable development.

References

- Floreano, D., Pericet-Camara, R., Viollet, S., Ruffier, F., Brückner, A., Leitel, R., Buss, W., Menouni, M., Expert, F., Juston, R. and Dobrzynski, M. K. (2013). Miniature curved artificial compound eyes. *Proceedings of the National Academy of Sciences*, 110(23): 9267-9272.
- Gidde, S. T. R. and Hutapea, P. (2020). Design and experimental evaluation of mosquito-inspired needle structure in soft materials. *Proceedings of the ASME International Mechanical Engineering Congress and Exposition*, 84-122.
- Gorb, S. N. (2011). Insect-inspired technologies: Insects as a source for biomimetics. In A. Vilcinskas (Ed.), *Insect Biotechnology*. pp.

241-264.

Hutapea, P. and Sahlabadi, M. (2018). Tissue deformation and insertion force of bee-stinger inspired surgical needles. *Journal of Medical Devices*, 12(3): 031008.

Nair, J. S., Kumar, S. T. and Anitha, N. (2024). Biomimetics: Insect - inspired technologies. *Journal of Tropical Agriculture*, 62(1): 41-50.



Plantation Crops: Green Wealth for Sustainable Livelihoods

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Abstract

Plantation crops play an important role in India's agricultural economy by supporting sustainable livelihoods and rural employment. Crops such as coconut, tea, coffee, rubber, arecanut and cocoa contribute significantly to farmers' income and foreign exchange earnings. Their perennial nature provides long-term and stable income to small and marginal farmers. Plantation crops also help in environmental protection by reducing soil erosion, improving soil fertility and conserving biodiversity. However, climate change has created challenges such as irregular rainfall, rising temperatures and increased pest and disease incidence. These factors affect crop productivity and farmers' livelihoods. Adoption of climate-resilient practices like agroforestry, intercropping, Integrated Pest Management and efficient water management helps reduce risks. With proper research support, technology and policy initiatives, plantation crops can continue to serve as India's green wealth for sustainable agriculture and livelihood security.

Introduction

India is blessed with a diverse climate that allows the cultivation of a variety of plantation crops such as coconut, tea, coffee, rubber, arecanut, cocoa and oil palm. These crops are not just plants they are the green backbone of the Indian agricultural economy. Plantation crops contribute significantly to employment generation, especially in rural areas, providing livelihoods to millions of small and marginal farmers, daily wage labourers and women workers. Economically, these crops play a major role in exports, earning valuable foreign exchange and boosting India's position in the global market. Beyond economics, plantation crops have industrial, nutritional and cultural importance.

Tea and coffee keep millions energized every morning, coconuts provide food, oil and raw materials and rubber supports a wide range of industries. Plantation crops also contribute to environmental sustainability. Their perennial nature helps prevent soil erosion, improve soil fertility and maintain biodiversity. With increasing awareness about climate change and sustainable farming, these crops are now recognized as key players in promoting eco-friendly agriculture while supporting rural livelihoods.

Major Plantation Crops of India

India is home to a rich diversity of plantation crops, each with its own economic, cultural, and environmental significance. Among these, coconut,

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tea, coffee, rubber, arecanut and cocoa stand out as the most important. Coconut, often called the “tree of life,” provides food, oil, Fiber and even fuel, making it indispensable to coastal communities. Tea, grown mainly in Assam, West Bengal, Kerala and Tamil Nadu, not only energizes millions every morning but also supports large-scale employment in plantations. Coffee, especially in Karnataka, Kerala and Tamil Nadu, has become a symbol of India’s specialty beverages and export potential.

Rubber plantations, mainly in Kerala and the northeastern states, produce latex that fuels industries like tires, gloves and medical equipment. Arecanut, widely grown in Karnataka and Kerala, has cultural and economic importance, particularly in traditional communities. Cocoa, though newer, is gaining attention for its role in the chocolate industry and value-added products.

Agro-Climatic Requirements and Growing Regions

Plantation crops thrive under specific climate and soil conditions, which is why their cultivation is concentrated in certain regions of India. Most of these crops prefer tropical and subtropical climates with well-distributed rainfall, warm temperatures, and high humidity. For example, coconut grows best in coastal areas with sandy, well-drained soil, while tea prefers hilly regions with acidic soil and cool, misty weather. Coffee flourishes in slightly elevated regions with rich, loamy soil and rubber requires warm, humid conditions with rainfall above 2000 mm. Arecanut grows well in fertile, well-drained

soils in coastal and hilly regions and cocoa thrives in shaded, humid, tropical climates. India’s major plantation zones are strategically spread across the country. Kerala, Karnataka and Tamil Nadu are famous for coconut, coffee and spices; Assam, West Bengal and Tamil Nadu dominate tea production; Kerala and northeastern states lead in rubber; Karnataka and Kerala are key arecanut regions. Cocoa cultivation is expanding in Kerala, Tamil Nadu, and Andhra Pradesh.

Economic Importance of Plantation Crops

Plantation crops are not just a source of food and raw materials. They are economic powerhouses that support millions of livelihoods across India. These crops provide direct employment to farmers, plantation workers and labourers in both rural and hilly regions, helping sustain families and communities. In terms of income generation, plantation crops like coconut, tea, coffee, rubber, arecanut and cocoa offer steady revenue for small and marginal farmers. Their perennial nature ensures that farmers have long-term and reliable income, unlike seasonal crops that may be affected by short-term weather fluctuations. On a larger scale, plantation crops contribute significantly to India’s foreign exchange earnings through exports. India is a leading global producer of tea and coffee and its coconut, rubber and cocoa products are in demand worldwide. This makes plantation agriculture a key player in strengthening the national economy.

Plantation Crops and Sustainable Livelihoods

Plantation crops are more than just a source

of income. They are a lifeline for millions of rural families. When cultivated responsibly, they help farmers maintain healthy soil, protect the environment and ensure steady production throughout the year. By adopting sustainable practices, farmers can secure their livelihoods while keeping their land fertile for future generations. One effective approach is soil testing and precise fertilization. Organizations like the Tea Board of India and Coffee Board encourage farmers to check their soil and leaf health regularly. This ensures fertilizers are applied in the right amount, saving money and protecting the soil. Similarly, the use of organic manures and green manure crops such as cattle manure, vermicompost, sun hemp, or cowpea enriches the soil naturally, improving fertility and plant growth.

Farmers also rely on mulching, terracing and contour bunds to maintain soil moisture and prevent erosion, especially in hilly regions like the Nilgiris and Wayanad. The addition of biofertilizers, like phosphate-solubilizing bacteria, further boosts nutrients while reducing dependence on chemicals. By combining these sustainable practices, plantation crops provide stable income, environmental protection and long-term security, making them a cornerstone of rural livelihoods in India.

Climate Change Impact on Plantation Crops

Plantation crops are highly sensitive to changes in climate, making them vulnerable to rising temperatures, erratic rainfall and extreme weather events. Crops like tea, coffee and cocoa require stable conditions to thrive and sudden changes can

stress the plants, reducing growth and productivity. These climate stresses often lead to yield fluctuations, directly affecting farmers' income. For example, delayed rains or prolonged dry spells can reduce nut and fruit formation in coconut and arecanut, while excessive rainfall may damage tea leaves or coffee cherries. Such unpredictable patterns make it difficult for farmers to plan harvesting and marketing effectively. Climate change also exacerbates pest and disease problems. Warmer and more humid conditions encourage the spread of fungal infections, insect infestations and viral diseases, which can devastate plantations if not managed carefully. To cope, farmers are increasingly adopting climate-resilient practices, including pest monitoring, resistant varieties and better water management, to safeguard both their crops and livelihoods.

Climate-Resilient Strategies in Plantation Crops

Indian plantation crops are increasingly facing the impacts of climate change in the form of heatwaves, droughts, floods and emerging pest outbreaks, making climate-resilient strategies a necessity rather than a choice. Farmers are now adopting drought-tolerant varieties, such as coconut cultivars Kalpa Raksha and Kalpa Tharu developed by CPCRI, which can withstand moisture stress.

Mixed planting and crop diversification help reduce the risk of total crop failure and provide additional income sources. Access to climate services, including weather forecasts, crop advisories and insurance schemes, enables farmers to make

timely decisions and manage risks more effectively. Plantation systems also contribute to carbon sequestration, as maintaining shade trees and organic matter allows them to act as natural carbon sinks. A good example is the “Climate Smart Coffee” initiative in Karnataka, which trains coffee growers in efficient water management, climate-resilient varieties and agroforestry practices, helping them adapt to changing climate conditions while securing sustainable livelihoods.

Integrated Pest Management (IPM) in Plantation Crops

In India, heavy dependence on chemical pesticides especially in tea estates of Assam and Kerala has raised serious health concerns and even led to export rejections due to pesticide residues. Plantation crops also face major pest problems such as the red palm weevil in coconut and stem borers in coffee, causing heavy yield losses.

To address these challenges, farmers are increasingly adopting Integrated Pest Management (IPM), which focuses on controlling pests in an eco-friendly and cost-effective manner. IPM practices include regular pest monitoring, use of light and pheromone traps and field scouting to detect pests early. Many tea plantations in the Nilgiris successfully use parasitic wasps to control tea mosquito bug, while coffee plantations in Karnataka apply fungal biological agents against coffee berry borer. The use of botanical pesticides such as neem oil and garlic-based sprays, along with cultural practices like pruning, sanitation and removal of

infected plants, has helped farmers reduce chemical use while maintaining healthy plantations.

Agroforestry Enhancement in Plantation Systems

India’s plantation regions often lie in ecologically sensitive areas such as the Western Ghats and Eastern Himalayas, where biodiversity conservation is crucial. Large-scale monoculture plantations can reduce ecosystem resilience, making crops more vulnerable to climate stress and pests. To overcome this, farmers are adopting agroforestry-based plantation systems that combine crops with trees and intercrops. In Karnataka, coffee plantations maintain native shade trees like *Albizia* and *Grevillea*, which improve soil health, conserve moisture and support beneficial insects and birds.



Coffee plantation under agroforestry system

Intercropping in Plantation Crops

Intercropping systems, such as growing black pepper, banana, or pineapple in coconut plantations, provide additional income while enhancing ecological stability. Moreover, preserving wildlife corridors and forest strips within plantation landscapes helps protect pollinators and natural pest predators. These agroforestry practices not only improve biodiversity but also make plantation farming more resilient, productive and sustainable in the long run.



Intercropping coconut with pineapple

Challenges and Future Prospects of Plantation Crops

Despite their economic and social importance, plantation crops in India face several challenges. Climate change, labour shortages, rising input costs, pest and disease outbreaks, and price fluctuations often affect productivity and farmers' income. Small and marginal farmers also struggle with limited access to quality planting material, modern technology and timely market information, making plantation farming increasingly demanding. However, the future of plantation crops remains promising due to continuous innovations in research and technology. The development of climate-resilient and high-yielding varieties, improved pest and disease management practices, digital tools for weather forecasting and mechanization are helping farmers overcome existing constraints. Value addition, organic certification and branding of plantation products are also opening new income opportunities. The way forward lies in adopting sustainable and climate-smart practices, strengthening farmer training and extension services and ensuring better policy support. With coordinated efforts from research institutions, government agencies and farmers, plantation crops can continue

to provide stable livelihoods, environmental benefits and economic growth, securing their role as India's green wealth for the future.

References

- Ganesh, M. C. (2010). Sustainable Practices for Growing Plantation Crops Successfully.
- Hebbar, K. B., Berwal, M. K. and Chaturvedi, V. K. (2016). Plantation crops: Climatic risks and adaptation strategies. *Indian Journal of Plant Physiology*, 21(4): 428-436.
- Raghuramulu, Y. (2010). Sustainable practices in Indian coffee plantations.
- Thamban, C. and Jaganathan, D. (2016). Extension approaches for sustainable development of plantation crops. *Innovative Extension Approaches for Plantation Crops, (Handbook)*, ICAR Central Plantation Crops Research Institute, Kasaragod, 1-21.
- Thomas, G. V. and Krishnakumar, V. (2024). Plantation crops and soil health management: an overview. *Soil Health Management for Plantation Crops: Recent Advances and New Paradigms*, 1-36.

Role of Bioinformatics in Modern Plant Breeding Applications

Nivetha A. L. and Vengatesh M.

Plant breeding has always relied on the ability to identify, select, and combine desirable traits from different plants to develop improved varieties. Traditionally, this process depended on field observation and phenotypic selection, which were often time-consuming and influenced by the environment. In recent decades, advances in molecular biology, genomics, and computational tools have transformed plant breeding. At the heart of this revolution lies bioinformatics the interdisciplinary science that combines biology, computer science, and statistics to analyze and interpret biological data. Bioinformatics helps plant breeders handle large-scale genomic information, identify genes controlling important traits, and make informed decisions faster and more accurately. It has become a core component of modern breeding, enabling data-driven and precision-based approaches to crop improvement.

What is Bioinformatics?

Bioinformatics refers to the application of computational tools and techniques to manage, analyze, and visualize biological data such as DNA, RNA, and protein sequences. It includes:

Data management: Storing and retrieving sequence and phenotypic data.

Sequence analysis: Identifying genes, markers, and genetic variations.

Functional genomics: Understanding gene expression and biological pathways.

Comparative genomics: Comparing genomes across species to identify conserved or unique genes.

Molecular modeling: Predicting the structure and function of proteins or enzymes.

In the context of plant breeding, bioinformatics helps integrate genomic, transcriptomic, proteomic, metabolomic, and phenomic data to accelerate breeding decisions.

Evolution of Bioinformatics in Plant Breeding

The journey of bioinformatics in plant breeding began with simple DNA sequence databases in the 1980s. Over time, technological advances such as Next-Generation Sequencing (NGS) and genome-wide association studies (GWAS) led to massive datasets that could not be analyzed manually. Today, bioinformatics tools support every stage of breeding:

- ✓ Genome sequencing and annotation
- ✓ Marker discovery and genotyping
- ✓ Trait mapping using QTL and GWAS
- ✓ Genomic selection and prediction
- ✓ Molecular modeling of gene function
- ✓ Data visualization and decision support

These applications have made breeding more efficient, predictive, and knowledge-driven.

Key Applications of Bioinformatics in Modern

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Plant Breeding

Genome Sequencing and Annotation

Bioinformatics enables the assembly and annotation of crop genomes, identifying genes linked to key traits like yield, disease resistance, and stress tolerance.

Example: The rice genome (*Oryza sativa*) and wheat genome were decoded using bioinformatics pipelines.

Tools: *BLAST*, *GeneMark*, *AUGUSTUS*, and *Ensembl Plants*.

Genome annotation helps breeders pinpoint candidate genes and understand their biological functions.

Molecular Marker Discovery

Bioinformatics helps identify DNA markers (SSR, SNP, InDel) associated with important traits.

- ✓ Large-scale genomic data are processed to locate single nucleotide polymorphisms (SNPs) linked to resistance or productivity.
- ✓ Software such as *TASSEL* and *PLINK* are used for association analysis.

Markers serve as a molecular signature, allowing breeders to track genes efficiently.

Marker-Assisted Selection (MAS)

In marker-assisted breeding, bioinformatics tools integrate marker data with phenotype information to select desirable genotypes.

- ✓ For example, identifying SNP markers associated with blast resistance in rice or high oil content in groundnut.
- ✓ Databases like *Gramene* and *PlantGDB* assist in

marker selection.

This approach saves time and resources by eliminating unwanted lines early in the breeding process.

Quantitative Trait Loci (QTL) Mapping and GWAS

QTL mapping and Genome-Wide Association Studies (GWAS) are statistical methods to locate genomic regions associated with complex traits such as yield, drought tolerance, or nutrient content.

- ✓ Bioinformatics manages the huge genotype × phenotype datasets required.
- ✓ Tools: *QTL Cartographer*, *TASSEL*, *GAPIT*, *GenStat*.

These analyses reveal candidate genes that can be used for targeted introgression or genomic selection.

Genomic Selection and Prediction

One of the most impactful applications of bioinformatics in breeding is genomic selection (GS). It uses genome-wide markers to predict the breeding value of individuals without phenotypic testing.

- ✓ Machine learning algorithms and statistical models (e.g., *RR-BLUP*, *GBLUP*, *Bayesian methods*) are applied.
- ✓ This helps breeders select superior lines faster and reduce breeding cycles.

For example, genomic selection in maize, rice, and wheat has accelerated genetic gain by 30–50%.

Important Bioinformatics Tools Used in Plant Breeding

Tool/Software	Application Area	Description
BLAST	Sequence alignment	Identifies similarity between DNA/protein sequences
TASSEL	GWAS & association mapping	Links genotypes with phenotypes
MEGA	Phylogenetic analysis	Constructs evolutionary trees
PLINK	SNP data analysis	Handles genotype datasets
Gene Mark / AUGUSTUS	Gene prediction	Annotates coding regions
Galaxy	Data integration	User-friendly bioinformatics workflows
Ensembl Plants / Gramene	Genomic databases	Access to annotated crop genomes
QTL Cartographer / GAPIT	QTL and genomic prediction	Identifies genomic regions linked to traits
R / Python	Statistical programming	Data analysis and visualization

Transcriptomics and Gene Expression Analysis

Bioinformatics analyzes RNA-seq data to study gene expression patterns under different conditions such as drought, salinity, or pest attack.

- ✓ Differential expression analysis identifies stress-responsive genes.
- ✓ Tools: *DESeq2*, *Cufflinks*, *EdgeR*.

This information helps design crops that perform better under abiotic and biotic stresses.

Comparative and Evolutionary Genomics

Comparing genomes of wild relatives and cultivated varieties reveals useful genes for breeding. Example: Comparative genomics between wild tomato (*Solanum pimpinellifolium*) and cultivated tomato identified alleles for disease resistance and nutrient quality.

Software: *OrthoMCL*, *MEGA*, *Clustal Omega*.

This expands the gene pool and helps introgress valuable traits from wild species.

Bioinformatics in Phenotyping and Data Integration

Modern breeding integrates phenomic data (growth, yield, quality) with genomic data using bioinformatics.

- ✓ Big-data platforms like *BreedBase* or *ICRISAT's BMS* connect field and lab data.

- ✓ Visualization tools help breeders make real-time, data-based decisions.

Case Studies and Success Stories

Rice (*Oryza sativa*): Bioinformatics identified Sub1A gene for submergence tolerance, leading to the development of Swarna-Sub1 variety.

- ✓ Data from genomic databases like *Gramene* were used to map tolerance genes.

Tomato (*Solanum lycopersicum*): Comparative genomics helped discover fruit size and flavor genes (*fw2.2*, *rin*) used in modern breeding.

Wheat (*Triticum aestivum*): Genome-wide SNP analysis through *TASSEL* and *GAPIT* enabled identification of QTLs for drought and rust resistance.

Groundnut (*Arachis hypogaea*): ICRISAT used bioinformatics pipelines for marker discovery and genomic selection, resulting in improved varieties tolerant to drought and aflatoxin.

These examples highlight how bioinformatics transforms raw data into actionable breeding strategies.

Integration with Artificial Intelligence (AI) and Machine Learning

Bioinformatics and AI are now merging to create smart breeding systems:

- ✓ Predicting gene-trait relationships using neural networks.
- ✓ Automating image-based phenotyping.
- ✓ Using AI algorithms for yield prediction and stress modeling. Platforms like *Deep Variant* and *Plant Village* already combine AI with genomics and phenomics.

This synergy marks the beginning of next-generation digital breeding.

Challenges in Applying Bioinformatics

Despite its potential, bioinformatics in plant breeding faces several limitations:

Data overload: Managing terabytes of genomic and phenomic data.

Lack of trained manpower: Limited bioinformatics expertise in many breeding institutions.

Software integration issues: Tools developed in isolation often lack compatibility.

Computational cost: High-end servers and cloud resources required.

Interpretation gaps: Translating data into meaningful biological insights remains complex.

Overcoming these challenges requires capacity building, infrastructure, and international collaboration.

Future Prospects

Pan-genomics: Studying the complete genetic diversity of crop species.

Metagenomics: Exploring soil and rhizosphere microbiome data for plant health.

Cloud-based breeding platforms: Enabling real-time collaboration and data sharing.

AI-driven genomic prediction: Enhancing accuracy and speed of selection.

Integration of omics: Combining genomics, proteomics, and metabolomics for holistic breeding.

The future breeder will work at the intersection of biology and data science, supported by powerful bioinformatics tools.

Conclusion

Bioinformatics has become the digital backbone of modern plant breeding. By enabling the storage, analysis, and interpretation of massive genomic datasets, it empowers breeders to make informed, data-based decisions. From decoding crop genomes to predicting superior hybrids, bioinformatics tools accelerate the development of high-yielding, resilient, and nutrient-rich varieties. As agriculture faces new challenges from climate change and food insecurity, bioinformatics-driven breeding will lead the way toward precision, sustainability, and innovation in global crop improvement.

Role of Doubled Haploid Technology in Rapid Varietal Development

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The demand for high-yielding, disease-resistant, and climate-resilient crop varieties is increasing globally to meet food and nutritional security. Traditional plant breeding methods, though effective, are time-consuming often requiring 8-10 years to develop a new stable variety. To overcome this limitation, Doubled Haploid (DH) technology has emerged as a revolutionary tool that can produce completely homozygous lines in just one generation, significantly reducing the breeding cycle time. Doubled haploid technology is now an integral part of modern plant breeding programs across cereals, vegetables, and industrial crops, offering breeders a faster, more reliable, and efficient way to develop improved varieties.

Concept of Doubled Haploid Technology

In conventional breeding, homozygosity is achieved after several generations of selfing. In contrast, DH technology allows the direct production of homozygous diploid plants from haploid cells (n), which contain only one set of chromosomes. These haploid cells are induced to double their chromosome number ($2n$) through spontaneous or artificial chromosome doubling to produce fertile, completely homozygous plants known as doubled haploids.

Key Steps

- ✓ Haploid induction (from gametes like pollen or

ovules)

- ✓ Chromosome doubling using agents such as colchicine or oryzalin
- ✓ Selection and regeneration of fertile plants

This technique ensures 100% genetic fixation in a single generation.

Methods of Doubled Haploid Production

Several biological approaches are used for DH production depending on the crop and reproductive biology.

Anther Culture (Androgenesis)

- ✓ Involves culturing anthers containing microspores (immature pollen grains).
- ✓ Widely used in rice, barley, wheat, and tobacco.
- ✓ Microspores are induced to form embryos, which regenerate into haploid plants.

Microspore Culture

- ✓ Isolates individual microspores instead of entire anthers.
- ✓ Allows better control and higher efficiency in some crops like Brassica and barley.

Gynogenesis (Ovary or Ovule Culture)

- ✓ Uses female gametophytic tissue (unfertilized ovule or embryo sac) for haploid induction.
- ✓ Effective in crops with poor androgenic response like onion, sugar beet and maize.

In Vivo Haploid Induction

- ✓ Uses genetic lines (haploid inducers) that trigger

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the development of haploid embryos after fertilization.

- ✓ Commonly used in maize breeding, where maternal haploids are produced.

Importance in Plant Breeding

Doubled haploid technology offers immense advantages for breeders working toward rapid and precise varietal improvement.

Rapid Development of Homozygous Lines

- ✓ Traditional selfing requires 6-8 generations; DH achieves full homozygosity in one step.
- ✓ Shortens breeding cycle from 10 years to about 2-3 years.

Enhanced Selection Efficiency

- ✓ Complete homozygosity allows accurate selection for desired traits like yield, disease resistance, or quality.
- ✓ Helps eliminate heterozygous segregants early in the breeding program.

Uniformity and Stability

- ✓ DH lines are genetically uniform and stable, ideal for testing and release as varieties or hybrid parents.

Accelerated Hybrid Development

- ✓ Homozygous parental lines for hybrids can be developed rapidly, expediting hybrid seed production.

Gene Mapping and Molecular Studies

- ✓ DH populations provide stable and uniform genetic material for QTL mapping, genomic selection, and marker-assisted breeding.

Applications in Major Crops

Cereals

Rice: Widely used for developing improved varieties through anther culture.

Wheat and Barley: DH lines used in hybridization and genetic analysis.

Maize: In vivo haploid induction has become standard in elite line development.

Oilseeds

Brassica species (rapeseed, mustard): Microspore culture for high oil content and stress tolerance.

Vegetables

Onion, cucumber and pepper: Gynogenesis and anther culture used to obtain uniform hybrid parents.

Industrial Crops

Tobacco and sugar beet: Among the earliest crops improved via DH methods for yield and quality traits.

Advantages of Doubled Haploid Technology

Benefit	Explanation
Speed	Reduces breeding time by 50-70%.
Efficiency	Achieves complete homozygosity in one generation.
Precision	Ensures true breeding lines without segregation.
Cost-effective	Reduces field generations and resource use.
Utility in Molecular Breeding	DH lines serve as ideal materials for marker validation and gene discovery.

Limitations and Challenges

Despite its promise, DH technology faces several constraints:

- ✓ Genotype dependency: Some varieties respond poorly in culture.
- ✓ Technical expertise and cost: Requires well-equipped tissue culture facilities.
- ✓ Albino plant formation in cereals like rice and wheat reduces recovery rates.

- ✓ Regulatory and bio safety aspects for genetically manipulated lines (in some cases).

Continuous research focuses on improving culture media, stress pretreatments, and haploid induction rates to overcome these limitations.

Recent Advances

Modern advancements have further improved the efficiency and scope of DH technology:

- ✓ CRISPR-based haploid induction through targeted gene edits.
- ✓ In vivo maternal haploid inducers in maize and rice.
- ✓ Automation and image-based selection for embryo identification.
- ✓ Integration with genomic selection to predict superior DH lines.

These innovations are transforming DH breeding from a specialized technique to a mainstream breeding tool.

Future Prospects

In the future, doubled haploid technology will:

- ✓ Play a vital role in speed breeding programs, integrating genomics and phenomics.
- ✓ Enable precision hybrid breeding, particularly under climate change conditions.
- ✓ Be extended to legumes and recalcitrant species through biotechnological advancements.
- ✓ Support pre-breeding and genetic resource management for new trait discovery.

With continued refinement, DH technology will remain a cornerstone of modern crop improvement, aligning with the global goal of faster,

sustainable, and resilient agriculture.

Conclusion

Doubled haploid technology has revolutionized the way plant breeders develop new varieties. By producing completely homozygous lines in a single generation, it drastically reduces time, cost, and uncertainty in breeding programs. Its integration with molecular and genomic tools offers limitless potential for precision agriculture, ensuring that future crop varieties are high-yielding, stress-tolerant, and nutritionally enhanced. Thus, DH technology stands as a powerful catalyst for rapid varietal development, making it a key driver of agricultural innovation and food security in the 21st century.

Organic Farming and Certification in India: Status, Challenges and Future Prospects

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Abstract

Organic farming has emerged as a sustainable alternative to conventional agriculture in response to declining soil health, environmental degradation, and rising consumer demand for safe food. In India, organic agriculture is gaining momentum due to government support, export opportunities, and increasing domestic awareness. India ranks among the leading countries in terms of number of organic producers and certified organic area. The certification system in India is governed by the Agricultural and Processed Food Products Export Development Authority through the National Programme for Organic Production (NPOP). Parallely, the Participatory Guarantee System (PGS-India) promotes local certification for domestic markets. This article discusses the concept, principles, current status, certification procedures, challenges, government initiatives, and future prospects of organic farming in India.

Introduction

Agriculture in India has undergone significant transformation since the Green Revolution. While productivity increased substantially, excessive use of chemical fertilizers and pesticides resulted in soil degradation, groundwater contamination, biodiversity loss, and health hazards. Organic farming offers a sustainable solution by promoting ecological balance, biodiversity conservation, and soil fertility enhancement without synthetic inputs. India has traditional roots in organic agriculture, as ancient farming systems relied on natural manures and crop

rotations. With growing health consciousness and export demand, organic farming has re-emerged as a promising sector contributing to sustainable rural development.

Concept and Principles of Organic Farming

Organic farming is a production system that avoids or largely excludes synthetic fertilizers, pesticides, growth regulators, genetically modified organisms (GMOs), and livestock feed additives.

The core principles include:

Health: Sustaining the health of soil, plants, animals, and humans.

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Ecology: Working with natural ecological cycles.

Fairness: Ensuring equity in environment and life opportunities.

Care: Responsible management for future generations.

Common organic practices

- ✓ Crop rotation
- ✓ Green manuring
- ✓ Composting and vermicomposting
- ✓ Biological pest control
- ✓ Use of biofertilizers
- ✓ Integrated farming systems

Current Status of Organic Farming in India

India is one of the leading countries in organic agriculture. According to the Ministry of Agriculture and Farmers Welfare, India has millions of hectares under organic certification (including wild harvest collection area). Major organic producing states:

- ✓ Madhya Pradesh
- ✓ Rajasthan
- ✓ Maharashtra
- ✓ Karnataka
- ✓ Uttar Pradesh
- ✓ Sikkim (first fully organic state)

India exports organic products such as

- ✓ Oilseeds
- ✓ Cereals and millets
- ✓ Tea and coffee
- ✓ Spices
- ✓ Cotton
- ✓ Fruits and vegetables

Key export destinations

- ✓ USA
- ✓ European Union
- ✓ Canada
- ✓ Australia

Certification System in India

Organic certification ensures that products meet defined organic standards. In India, certification operates under two major systems:

National Programme for Organic Production (NPOP):

The NPOP is implemented by the Agricultural and Processed Food Products Export Development Authority (APEDA). It regulates standards for organic production and export.

Key features

- ✓ Accreditation of certification bodies
- ✓ Inspection and verification of farms
- ✓ Compliance with international standards
- ✓ Mandatory for export of organic products

Steps for certification

- ✓ Application to accredited certification body
- ✓ Farm inspection
- ✓ Conversion period (2-3 years)
- ✓ Annual inspections
- ✓ Issuance of organic certificate

Participatory Guarantee System (PGS-India):

PGS-India is managed by the Ministry of Agriculture and Farmers Welfare.

Features

- ✓ Low-cost certification
- ✓ Group-based verification
- ✓ Suitable for small and marginal farmers

- ✓ Primarily for domestic markets

PGS relies on peer reviews and mutual trust among farmers.

Government Initiatives Supporting Organic Farming:

Several schemes promote organic agriculture:

- ✓ Paramparagat Krishi Vikas Yojana (PKVY)
- ✓ Mission Organic Value Chain Development for North Eastern Region (MOVCDNER)
- ✓ National Mission for Sustainable Agriculture (NMSA)
- ✓ Financial support for certification and organic inputs

These programs aim to increase area under organic farming, improve farmer income, and promote sustainable practices.

Benefits of Organic Farming

Environmental Benefits

- ✓ Improved soil structure and fertility
- ✓ Increased microbial activity
- ✓ Reduced water pollution
- ✓ Biodiversity conservation

Economic Benefits

- ✓ Premium price for organic produce
- ✓ Export opportunities
- ✓ Reduced input cost in long term

Health Benefits

- ✓ Reduced chemical residues
- ✓ Safer food for consumers

Challenges in Organic Farming and Certification

Despite growth, organic farming faces several challenges:

- ✓ Yield reduction during transition period
- ✓ High certification cost
- ✓ Lengthy conversion period
- ✓ Lack of awareness among farmers
- ✓ Marketing and supply chain constraints
- ✓ Risk of contamination from neighboring conventional farms

Certification complexity discourages small farmers unless supported through group certification models.

Comparison: Organic vs Conventional Farming

Parameter	Organic Farming	Conventional Farming
Inputs	Natural	Synthetic
Soil Health	Improves over time	Often degrades
Yield	Moderate	High (initially)
Cost	Lower long-term	High input cost
Market Price	Premium	Normal

Future Prospects of Organic Farming in India

The future of organic agriculture in India appears promising due to:

- ✓ Growing domestic demand
- ✓ Expansion of e-commerce platforms
- ✓ Increasing health awareness
- ✓ Government policy support
- ✓ Export market growth
- ✓ Climate change mitigation role

Digital traceability systems and blockchain-based certification may improve transparency in future. Integration of organic farming with climate-smart agriculture and carbon credit markets can further enhance sustainability.

Conclusion

Organic farming in India represents a sustainable pathway toward ecological balance, soil health restoration, and improved farmer income.

With structured certification systems such as NPOP and PGS-India, India has established a credible regulatory framework. However, addressing challenges related to yield, certification cost, and market access is essential for large-scale adoption. Strengthening farmer awareness, research support, and value chain development will ensure that organic farming contributes significantly to India's agricultural sustainability and economic growth.

References

Ministry of Agriculture and Farmers Welfare.

Reports on Organic Farming in India.

APEDA. National Programme for Organic Production (NPOP) Guidelines.

Government of India. Paramparagat Krishi Vikas Yojana Guidelines.

Research articles on organic farming systems and sustainability (2018-2024).

Artificial Intelligence for Disease Prediction in Vegetable Crops

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Abstract

Vegetable crops are highly susceptible to a wide range of diseases that significantly reduce yield, quality, and economic returns. Early detection and prediction of plant diseases are essential for effective crop management and sustainable agricultural production. Traditional disease detection methods mainly rely on visual inspection and laboratory analysis, which are often time-consuming and require expert knowledge. In recent years, artificial intelligence (AI) has emerged as a promising technology for improving plant disease diagnosis and prediction. AI techniques such as machine learning, deep learning, and computer vision enable automated detection of plant diseases through image analysis and monitoring of environmental data. Convolutional neural networks (CNNs) and other deep learning models have shown high accuracy in identifying disease symptoms from plant leaf images. Moreover, the integration of AI with advanced technologies such as the Internet of Things (IoT), drones, and remote sensing systems has enhanced real-time crop monitoring and disease forecasting. These technologies allow farmers to detect diseases at an early stage and apply targeted management practices, thereby reducing crop losses and minimizing excessive pesticide use. Despite several advantages, challenges such as limited datasets, variability in field conditions, and the need for technical expertise still hinder the widespread adoption of AI technologies in agriculture. However, continuous advancements in digital agriculture and data analytics are expected to improve the efficiency and accessibility of AI-based disease prediction systems. The application of artificial intelligence in vegetable crop disease management has the potential to enhance productivity, support precision agriculture, and contribute to sustainable food production systems.

Introduction

Vegetable crops play a crucial role in global food and nutritional security because they are rich sources of vitamins, minerals, and antioxidants. However, vegetable production is often affected by various diseases caused by fungi, bacteria, viruses, and nematodes. These diseases can significantly reduce crop yield and quality, leading to major economic losses for farmers.

Traditional disease detection methods rely mainly on visual inspection by farmers or plant pathologists, which is time-consuming and often inaccurate at early stages of infection. In recent years, artificial intelligence (AI) has emerged as an innovative technology for improving crop monitoring and disease management. AI techniques such as machine learning, deep learning, and computer vision can analyse large datasets and detect disease symptoms

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at an early stage. These technologies enable rapid and automated diagnosis of plant diseases and support timely decision-making in agricultural management.

Importance of disease prediction in vegetable crops

Vegetable crops such as tomato, potato, cucumber, pepper, and cabbage are highly susceptible to different plant diseases. For example, diseases such as late blight, powdery mildew, bacterial wilt, and leaf spot frequently cause severe yield losses in vegetable production systems. Early prediction of these diseases is essential to reduce crop damage and ensure effective disease management strategies. Traditional disease diagnosis methods depend heavily on expert knowledge and laboratory testing, which may not always be available to farmers. AI-based disease prediction systems can analyse plant images and environmental conditions to identify diseases quickly and accurately. Such technologies help farmers detect diseases at an early stage and apply control measures before the disease spreads across the field.

Role of artificial intelligence (AI) in disease prediction

Artificial intelligence refers to computer systems that can perform tasks requiring human intelligence, including learning, reasoning, and problem-solving. In agriculture, AI techniques are widely used to analyse plant images and environmental data to detect and predict crop diseases. AI-based disease prediction systems generally involve

several steps, including data collection, data preprocessing, model training, and disease classification. Images of plant leaves are captured using smartphones, cameras, or drones and then processed using AI algorithms to detect symptoms such as spots, discoloration, and lesions. These systems can analyse large numbers of images and provide accurate disease predictions in real time.

Machine learning and deep learning techniques

Machine learning algorithms such as decision trees, support vector machines, and random forest models are commonly used to analyse the relationship between environmental conditions and disease occurrence. These models can predict disease outbreaks based on factors such as temperature, humidity, and rainfall patterns. Deep learning techniques, particularly convolutional neural networks (CNNs), have shown excellent performance in plant disease detection. CNN models automatically extract important features from plant images and classify them into healthy or diseased categories. Studies have shown that deep learning models can achieve very high accuracy in detecting plant diseases from leaf images.

Integration of AI with smart agriculture technologies

The application of AI becomes more powerful when integrated with modern technologies such as the Internet of Things (IoT), sensors, and drones. IoT-based sensors can continuously monitor environmental parameters such as temperature, humidity, soil moisture, and light intensity.

These data are transmitted to AI systems that analyse the information and predict potential disease outbreaks. Drones equipped with high-resolution cameras can capture aerial images of vegetable fields and identify infected plants using AI-based image analysis. This allows farmers to detect disease-affected areas quickly and apply targeted treatments to prevent further spread.

Advantages of AI in vegetable disease management

The use of artificial intelligence in vegetable crop disease prediction offers several advantages. AI systems enable early detection of plant diseases, which helps reduce crop losses and improve productivity. These systems can process large volumes of data quickly and provide accurate results, making them more reliable than traditional disease detection methods. In addition, AI-based monitoring systems reduce the need for manual field inspection and help farmers optimize the use of pesticides and other agricultural inputs. This contributes to sustainable agricultural practices and reduces environmental pollution.

Challenges and limitations

Despite the promising benefits, several challenges still exist in the application of AI in agriculture. One major limitation is the availability of large and diverse datasets required for training AI models. Many existing datasets contain images captured under controlled conditions, which may not accurately represent field conditions. Another challenge is the need for advanced computational

resources and technical expertise to develop and implement AI systems. In developing countries, limited access to digital infrastructure may restrict the adoption of these technologies by smallholder farmers.

Conclusion

Artificial intelligence is revolutionizing agricultural practices by providing advanced tools for crop monitoring and disease management. AI-based disease prediction systems enable early detection and accurate diagnosis of plant diseases, helping farmers take timely preventive measures. Techniques such as machine learning, deep learning, and computer vision have demonstrated significant potential in detecting diseases in vegetable crops such as tomato, potato, and cucumber. Although challenges related to data availability and infrastructure remain, continuous advancements in AI technology are expected to improve the efficiency and accessibility of disease prediction systems. The integration of AI with modern agricultural technologies will play a vital role in achieving sustainable vegetable production and ensuring global food security.

References

- Ferentinos, K. P. (2018). Deep learning models for plant disease detection and diagnosis. *Computers and Electronics in Agriculture*, 145: 311-318.
- Kamilaris, A. and Prenafeta-Boldú, F. X. (2018). Deep learning in agriculture: A survey. *Computers and Electronics in Agriculture*,

147: 70-90.

- Mohanty, S. P., Hughes, D. P. and Salathé, M. (2016). Using deep learning for image-based plant disease detection. *Frontiers in Plant Science*, 7: 1419.
- Sladojevic, S., Arsenovic, M., Anderla, A., Culibrk, D. and Stefanovic, D. (2016). Deep neural networks based recognition of plant diseases by leaf image classification. *Computational Intelligence and Neuroscience*, 2016: 1-11.
- Too, E. C., Yujian, L., Njuki, S. and Yingchun, L. (2019). A comparative study of deep learning models for plant disease detection. *Computers and Electronics in Agriculture*, 161: 272-279.
- Devarajan, D., Allafi, R., Obayya, M. and Nemri, N. (2026). AI-based real-time disease diagnosis in plants using deep learning driven convolutional neural networks. *Scientific Reports*, 16: 4587.
- Sujatha, R., Krishnan, S., Chatterjee, J. M. and Gandomi, A. H. (2025). Advancing plant leaf disease detection integrating machine learning and deep learning. *Scientific Reports*, 15: 11552.
- Mishra, U., Pandey, A., Logeswari, G. and Tamilarasi, K. (2026). Deep learning-based disease detection in crop plants using convolutional neural networks. *Scientific Reports*.
- Singh, T. D. and Bharti, R. (2023). Detection and classification of plant diseases in tomato using deep learning techniques: A review. *Asian Journal of Computer Science and Technology*, 12(2): 39-47.
- Roy, A. M., Bose, R. and Bhaduri, J. (2021). A fast accurate fine-grain object detection model based on YOLOv4 deep neural network for plant disease detection. *arXiv preprint arXiv: 2111.00298*.
- Thakur, P. S., Khanna, P., Sheorey, T. and Ojha, A. (2022). Explainable vision transformer enabled convolutional neural network for plant disease identification. *arXiv preprint arXiv: 2207.07919*.
- Oni, M. K. and Prama, T. T. (2025). Optimized convolutional neural network for real-time tomato leaf disease detection. *arXiv preprint arXiv: 2502.18521*.
- Gohil, M. K., Bhattacharjee, A., Rana, R., Lal, K., Biswas, S. K., Tiwari, N. and Bhattacharya, B. (2024). A hybrid technique for plant disease identification and localisation in real time. *arXiv preprint arXiv: 2412.19682*.

Intensity Rate of Yellow Stem Borer (*Scirpophaga incertulas*) in Rice: A Case Study from Purvanchal Region, U.P.

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Abstract

Yellow Stem Borer (*Scirpophaga incertulas*) is a major pest of rice in Eastern Uttar Pradesh, causing severe damage during both vegetative and reproductive stages. A study was conducted from *Kharif* season July to October 2024 at Deoria to Kushinagar region, to assess its infestation and biology. Infested plants showed 'dead heart' and 'whitehead' symptoms, leading to significant yield loss. Eggs were laid in clusters on leaf tips and hatched in 6-7 days. Larvae passed through 4-6 instars over 29-40 days and pupated within the stem. Adult moths lived 6-10 days, with females laying up to three egg masses. Field and lab observations confirmed the pest's damaging potential and prevalence in the region. About 34% prospective losses. Regular monitoring and integrated pest management strategies are essential to control *S. incertulas* and minimize crop loss.

Introduction

Purvanchal, located in the eastern part of Uttar Pradesh, is characterized by a semi-arid agro-climatic zone where cropping patterns are largely dependent on the monsoon. Major crops cultivated in this region include rice, sugarcane, wheat, pigeonpea, groundnut, maize, bajra, urd bean, and a variety of vegetables grown during both *kharif* and *rabi* seasons. These crops are often heavily infested by various insect pests, leading to significant economic losses. At the college farm in this region, *kharif* crops such as rice, groundnut, maize, and pigeonpea are routinely cultivated. During a general inspection of the rice fields, a notable infestation of Yellow Stem Borer (*Scirpophaga incertulas*) (Lepidoptera: Pyralidae) larvae was observed, prompting a detailed study to assess the extent of

damage caused by this pest. Yellow Stem Borer (YSB) is a highly Monophagous and destructive pest of deep-water rice, prevalent across Asian rice-growing regions. Yield losses due to YSB infestation are estimated to range from 15 to 20%, with potential losses of up to 60% under severe conditions (Chatterjee, 2014). The larvae bore into rice stems, causing 'dead hearts' during the vegetative stage, which results in the loss of productive tillers. At the reproductive or maturity stage, they cause 'white ear' formation, severely affecting grain development and overall yield.

Female moths of YSB lay eggs in clusters of 100 to 200 near the leading edges of leaf blades. Under sunny conditions, the eggs hatch within 6 to 8 days. The larval stage is the most damaging, consisting of six instars over a developmental period

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of 21 to 29 days. Pupation occurs inside the rice stem, typically just above the waterline or in the plant's lowest node. Depending on the ambient temperature, the pupal stage lasts approximately 5 to 7.5 days (Manikandan *et al.*, 2013). Given the economic impact and severity of the infestation, this study was undertaken to investigate the occurrence, life cycle, and damage potential of *Scirpophaga incertulas* in rice crops of the Purvanchal region.

Observation Process of Yellow Stem Borer

Routine field inspections revealed larval infestations during both the vegetative and reproductive stages of the rice crop. Scheduled visits were carried out at 10-day intervals to assess pest occurrence and progression. Symptoms of YSB damage, including 'dead heart' and 'white ear' formation, were systematically recorded. Collected specimens were identified, and the various developmental stages of the insect were studied under laboratory conditions. Detailed morphological observations were made to support accurate identification and characterization of the pest.

Intensity Rate of Yellow Stem Borer: (*Scirpophaga incertulas*) on Paddy under Purvanchal Region of Uttar Pradesh

The Yellow Stem Borer (*Scirpophaga incertulas*) (Lepidoptera: Pyralidae) has emerged as a significant pest of rice in the Purvanchal region of Eastern Uttar Pradesh, particularly affecting crops grown under monsoon-dependent semi-arid conditions. A study was conducted from July to October 2024 at Deoria to Kushinagar region, to

monitor the incidence, damage symptoms, and biological characteristics of this pest. The inspection of paddy fields at 10-day intervals revealed larval infestation during both vegetative and reproductive stages of the rice crop. Initial damage caused by young larvae involves boring and feeding within the leaf sheath, resulting in broad, longitudinal, whitish, discolored areas. While this early-stage feeding does not typically cause leaf wilting, more severe damage occurs when larvae bore into the stem about a week after hatching. This internal feeding detaches the upper plant parts from the base, producing typical 'dead heart' symptoms during the vegetative stage. In such cases, the central leaf whorl fails to unfurl, dries, and turns brown, while the lower leaves remain green. These affected tillers ultimately fail to bear panicles, leading to a reduction in productive tiller count. During the reproductive phase, larval feeding results in 'whitehead' symptoms, characterized by dried, empty, upright panicles that fail to bear grain. In some instances, panicle formation is aborted entirely or results in poorly developed, shriveled spikelets, severely compromising yield potential.

Detailed laboratory observations further confirmed the biological stages of *S. incertulas*. Eggs were found deposited in clusters of 100-200 at the tips of rice leaves, creamy white in color, flat, and oval-shaped, with an incubation period of 6-7 days. The larvae, cream-colored with reddish-brown heads, measured from 1.5 mm upon hatching to up to 20 mm in their final instars. The larval stage lasted approximately 29-40 days, with individuals under-

going four to six instars. The first instar larvae were non-motile and remained near the hatching site, while second to fourth instar larvae were creamy white. The fifth instar appeared dirty white, and the sixth instar transitioned to a greenish-yellow or yellowish-white coloration (Panigrahi and Rajamani, 2008). Fully developed larvae bored exit holes and migrated to other tillers or underwent pupation within the stem, usually at the plant base or slightly below the soil surface. Pupae were dark brown, and the pupal stage lasted between 6 and 10 days, depending on ambient conditions.

Adult moths emerged shortly thereafter, with females noticeably larger than males. Female moths possessed bright yellowish-brown forewings marked by a distinct central black spot, with a wingspan ranging from 24 to 36 mm. They exhibited nocturnal activity and had a lifespan of 6 to 10 days, during which each female could lay up to three egg masses. This high reproductive potential, combined with overlapping generations and favorable climatic conditions, contributes to the pest's persistence and widespread distribution. The results of this study confirm a significant level of infestation by Yellow Stem Borer in paddy fields of Eastern Uttar Pradesh. These findings are consistent with earlier reports, such as Rahaman *et al.* (2014), which indicated that *S. incertulas* constitutes approximately 70% of stem borer populations in regions like Bangladesh and Sirvi *et al.* (2021), which detailed the developmental biology of the pest.

Conclusion

The presence of this pest in both early and late crop stages highlights its destructive potential and its threat to rice productivity. Therefore, regular field monitoring and the implementation of integrated pest management (IPM) practices are critical to minimize economic losses and ensure sustainable rice cultivation in this vulnerable agro-ecological zone. Encourage natural enemies such as: Egg parasitoids: *Trichogramma japonicum* and the release in rate of @ 50,000-100,000 parasitoids/ha at weekly intervals can reduce infestation. At last apply insecticides only when the Economic Threshold Level (ETL) is reached after showing symptoms 5% of dead heart (vegetative stage) and 2% white ear (reproductive stage). The recommended insecticides are Chlorantraniliprole, Cartap hydrochloride, Flubendiamide and Fipronil as per infestation rate for better control.

References

- Chatterjee, S. M. P. (2014). Management of rice yellow stem borer, *Scirpophaga incertulas* Walker using some biorational insecticides. *Journal of Bio-pesticides*, 7: 1-5.
- Manikandan, N., Kennedy, J. S. and Geethalakshmi, V. (2013). Effect of elevated temperature on development time of rice yellow stem borer. *Indian Journal of Science and technology*, 6(12): 5563-5566.
- Panigrahi, D. and Rajamani, S. (2008). Studies on the biology and reproductive behavior of yellow stem borer, *Scirpophaga incertulas* Walker. *Indian Journal of Entomology*, 45(1): 137.

- Rahaman, M. M., Islam, K. S., Jahan, M. and Mamun M. A. A. (2014). Relative abundance of stem borer species and natural enemies in rice ecosystem at Madhupur, Tangail, Bangladesh. *Journal of Bangladesh Agriculture University*, 12(2): 267-272.
- Sirvi, M., Seervi, S. and Kumar P. (2021). Mark of identification. *Journal of Entomological Reserach*, 1(11): 3-6.



Value Addition Strategies for Minor and Indigenous Vegetables

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Abstract

Minor and indigenous vegetables play an important role in improving nutritional security, biodiversity conservation and livelihood opportunities for smallholder farmers. Despite their rich nutritional value and adaptability to local climates, many of these crops remain underutilized due to limited market demand, poor post-harvest handling and lack of processing technologies. Value addition offers an effective strategy to enhance the marketability and economic value of these vegetables. Processing techniques such as drying, pickling, fermentation and packaging can extend shelf life, reduce post-harvest losses and create new market opportunities. By integrating traditional knowledge with modern food processing technologies, farmers and entrepreneurs can transform minor vegetables into value-added products. This article explores the importance of indigenous vegetables, various value addition strategies, marketing opportunities and the role of innovation in promoting sustainable utilization of these nutritious crops.

Introduction

Minor and indigenous vegetables have long been part of traditional diets in many regions of the world. These crops are often well adapted to local environmental conditions and require fewer inputs compared to major vegetable crops. Examples include drumstick leaves, amaranthus, ivy gourd, bitter gourd and snake gourd. Despite their nutritional richness and climate resilience, these vegetables receive limited attention in commercial agriculture. One of the main reasons is their short shelf life and low market visibility. Value addition through processing and improved marketing can significantly increase their economic potential. Promoting value-added products from indigenous vegetables can improve farmer incomes, support rural enterprises and enhance consumer awareness of

healthy food options.

Importance of Minor and Indigenous Vegetables

Minor vegetables contribute significantly to dietary diversity and nutrition. Many indigenous vegetables are rich sources of vitamins, minerals, antioxidants and dietary fiber. They also play a role in maintaining agro-biodiversity and supporting sustainable farming systems. Because these crops are often tolerant to drought, pests and poor soil conditions, they are particularly valuable in climate-resilient agriculture. Promoting their cultivation and utilization can reduce dependency on a limited number of commercial crops and improve food system sustainability. Furthermore, these vegetables are often affordable and accessible to rural communities.

Need for Value Addition

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Value addition is the process of increasing the economic value of agricultural products through processing, packaging and improved marketing. Minor vegetables are highly perishable and often suffer from post-harvest losses due to poor storage and transportation facilities. Processing these vegetables into products such as powders, pickles, dried flakes and ready-to-cook mixes can significantly extend their shelf life. Value addition also helps diversify products and create new market opportunities for farmers and small-scale food processors. By developing attractive packaging and branding strategies, indigenous vegetables can gain greater consumer acceptance.

Processing Techniques for Value Addition

Various processing methods can be applied to minor vegetables to improve their shelf life and market value. Drying is one of the most common techniques used to preserve leafy vegetables such as moringa and amaranthus. Pickling and fermentation are traditional methods that enhance flavor and nutritional properties. Freezing and dehydration technologies also help retain the quality of vegetables during storage. Additionally, vegetables can be processed into powders or flakes that can be used in soups, sauces and health supplements.



Adoption of these technologies allows farmers and entrepreneurs to create innovative food products from locally available vegetables.

Role of Entrepreneurship and Small-Scale Industries

Value addition in minor vegetables offers significant opportunities for rural entrepreneurship and small-scale industries. Women's self-help groups and farmer producer organizations can play an important role in processing and marketing value-added vegetable products. Establishing small processing units in rural areas can generate employment and strengthen local economies. Government programs and agricultural extension services also support value-added enterprises through training, financial assistance and infrastructure development. Encouraging agripreneurship in vegetable processing can contribute to sustainable rural development.

Marketing and Consumer Awareness

Successful promotion of value-added vegetable products depends on effective marketing strategies and consumer awareness. Many consumers are unaware of the nutritional benefits of indigenous vegetables. Awareness campaigns, food festivals and educational programs can help promote their consumption. Attractive packaging, labeling and branding can also enhance product appeal in urban markets. Developing value chains that connect farmers, processors and retailers is essential for ensuring consistent supply and fair pricing. With growing interest in healthy and organic foods, indigenous vegetables have great potential in modern

markets.

Challenges in Value Addition

Despite the benefits of value addition, several challenges hinder the widespread adoption of processing technologies for minor vegetables. Limited access to processing equipment, lack of technical knowledge and inadequate storage facilities are major constraints. Small farmers often face difficulties in accessing markets and maintaining product quality standards. In addition, inconsistent supply of raw materials can affect processing operations. Addressing these challenges requires improved infrastructure, training programs and supportive government policies.

Future Prospects

The future of value addition in minor and indigenous vegetables is promising as consumers increasingly demand nutritious and sustainable food products. Advances in food processing technologies, improved supply chains and digital marketing platforms can expand the reach of value-added vegetable products. Research institutions are also exploring innovative techniques to enhance product quality and nutritional value. Promoting these vegetables through policy support, entrepreneurship development and public awareness can transform them into valuable components of modern food systems.

Conclusion

Minor and indigenous vegetables have immense potential to contribute to nutrition, sustainability and rural livelihoods. However, their

full potential can only be realized through effective value addition strategies. Processing technologies, improved packaging and better marketing approaches can enhance the economic value of these crops. Encouraging entrepreneurship and strengthening value chains will further support the development of value-added vegetable products. By integrating traditional knowledge with modern innovation, minor vegetables can play a significant role in promoting healthy diets and sustainable agriculture.

References

- FAO. (2022). The importance of underutilized crops for sustainable food systems. Food and Agriculture Organization of the United Nations.
- Keatinge, J. D. H., Yang, R. Y., Hughes, J. D., Easdown, W. J. and Holmer, R. (2021). The importance of vegetables in ensuring both food and nutritional security in developing countries. *Food Security*, 13(2): 337-353.
- Mabhaudhi, T., *et al.* (2022). Indigenous vegetables as a solution to food and nutrition security in developing countries. *Sustainability*, 14(6): 3452.
- Osei-Kwarteng, M., *et al.* (2021). Processing and value addition of indigenous vegetables for improved livelihoods. *Journal of Food Processing and Preservation*, 45(8): e15678.
- Sarkar, D., *et al.* (2023). Underutilized crops and value addition for sustainable agriculture. *Agronomy*, 13(2): 401.

Effect of Tillage Practices on Soil Organic Matter

S. L. Bankar

Abstract

Soil Organic Matter (SOM) is the backbone of healthy and productive soils. It improves soil structure, enhances nutrient availability, increases water-holding capacity, and supports beneficial soil organisms. Among the many agronomic practices influencing SOM, tillage plays a crucial role. The way soil is tilled its intensity, depth, and frequency has a direct effect on the quantity and stability of organic matter present in the soil. Management practices including various tillage systems influence quantity and composition of soil organic matter (SOM). Parameters for evaluating both the SOM quantity (organic C, total N) and quality (microbial biomass C, hydrophobic and hydrophilic organic components) were determined in soil samples, taken from two soil depths (0-0.1 m and 0.1-0.3 m) in a field experiment in the period 2001-2007, with different tillage systems. The experiment, founded in 1995 in Prague-Ruzyně, includes conventional soil tillage (CT) plus some selected methods of conservation tillage: (a) no tillage, (b) no tillage + mulch, and (c) minimum tillage with pre-crop residues incorporated. Cox and microbial biomass C contents increased significantly with conservation tillage as compared to CT in 0-0.1 m layer, non-significant increase was found in 0.1-0.3 m layer. Nt increased non-significantly in both layers. Along with the depth of sampling, the content of the characterized parameters decreased in all variants; but the decrease in the conventionally tilled variant was, for the most part, lower than in the conservation tillage. The functional hydrophobic and hydrophilic groups of soil organic matter were identified by Fourier transform infrared (FTIR) spectroscopy, and the hydrophobic/ hydrophilic group intensities ratio was calculated as the parameter of soil hydrophobicity.

Introduction

Tillage generally decreases soil organic matter (SOM) by breaking up soil aggregates, exposing organic matter to faster decomposition, and releasing stored carbon as CO₂. Conversely, conservation tillage, which minimizes soil disturbance, tends to increase or maintain SOM over time by protecting soil aggregates and promoting biological activity. The negative effects of intensive tillage include reduced SOM, lower nutrient retention, and

increased erosion, while conservation methods improve soil health. Tillage method affects sustainable use of soil resources through its influence on soil quality. Tillage systems; particularly conventional tillage system, adversely affect soil quality by damaging soil structure, decreasing soil moisture content, increasing soil bulk density and root penetration resistance. Tillage refers to the mechanical manipulation of soil using tools such as ploughs, cultivators, rotavators, and harrows.

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Sorghum and maize are high-nutrient demanding crops compared with other cereals. These crops require both the major nutrients (N, P and K) and the secondary nutrients (Zn, S, Mg, Ca, B, Fe, Cl, Cu etc.) in adequate amount to ensure good root establishment, vigorous and healthy growth, and increased yield. Traditionally used for seedbed preparation, weed control, and residue incorporation, tillage can be classified into:

1. Conventional Tillage (CT)
2. Reduced Tillage (RT)
3. Zero/No-till (NT)
4. Minimum Tillage (MT)
5. Deep Tillage (DT)

Each system impacts soil organic matter differently.

Effect of Tillage on Soil Organic Matter

Conventional Tillage Reduces Soil Organic Matter: Conventional tillage involves repeated ploughing and pulverization of soil, exposing it to air. This leads to:

- ✓ Rapid decomposition of organic matter due to increased microbial activity.
- ✓ Loss of carbon through oxidation.
- ✓ Soil erosion, which removes nutrient-rich topsoil.
- ✓ Lower residue retention, resulting in reduced organic inputs.

Over time, continuous heavy tillage causes a decline in soil organic matter making soils less fertile, more compacted, and moisture-deficient.

Reduced or Minimum Tillage Slows Organic Matter Loss: Reduced or minimum tillage disturbs

the soil less frequently and to shallower depths. Its benefits include:

- ✓ Slower decomposition of organic carbon, helping retain SOM.
- ✓ Better soil aggregation, reducing erosion.
- ✓ More crop residues left on the surface, adding organic inputs.

However, SOM improvements are moderate if residue retention is not practiced.

No-Till Improves SOM and Soil Health: No-till systems leave soil undisturbed except for narrow strips for seeding. This system has shown strong positive effects on soil organic matter:

- ✓ Enhances carbon sequestration, building SOM over time.
- ✓ Reduces erosion by keeping residues intact on surface.
- ✓ Improves microbial and earthworm activity, which stabilizes organic matter.
- ✓ Promotes long-term soil fertility and moisture conservation.

No-till is considered one of the most effective methods for SOM improvement, especially when combined with residue mulching and crop rotation.

Deep Tillage has Mixed Effects: Deep tillage breaks hard pans and improves root penetration but can:

- ✓ Expose deeper soil layers to oxidation.
- ✓ Cause temporary SOM loss.

Occasional deep tillage may help in compacted soils, but frequent deep tillage accelerates organic matter decomposition.

Influence of Tillage Carbon Cycling

Tillage acts as a stimulant to soil microbes by increasing aeration. This speeds up microbial decomposition of organic residues and converts stable organic matter into CO₂.

More tillage = More carbon loss

Less tillage = More carbon sequestration

Preserving SOM is critical for climate-smart agriculture because soil is one of the largest carbon sinks on Earth.

Strategies to Maintain or Improve Soil Organic Matter

To sustain soil fertility, farmers can adopt practices that minimize disturbance and enhance carbon inputs:

- ✓ Reduced or No-till Farming
- ✓ Decreases SOM loss and improves soil structure.
- ✓ Residue Retention or Mulching
- ✓ Surface residues protect soil and add organic carbon.
- ✓ Crop Rotation with Legumes & Cover Crops
- ✓ Improves biomass addition and soil biodiversity.
- ✓ Organic Manure & Compost Application
- ✓ Boosts nutrient cycling and SOM content.
- ✓ Avoiding Excessive Tillage
- ✓ Prevents breakdown of stable soil carbon.

Conclusion

Tillage remains an essential tool in modern agriculture, but its intensity must be managed carefully. Conventional tillage accelerates the loss of soil organic matter, while practices like reduced tillage and no-till farming help preserve and gradu-

ally build SOM. By adopting conservation tillage, residue management and crop diversification, farmers can improve soil health, enhance productivity and contribute to long-term sustainability.

References

- Chenu, C. Y., Le Bissonnais and Arrouays, D. (2000). Organic matter influence on clay wettability and soil aggregate stability. *Soil Science Society of America Journal*, 64: 1479-1486.
- Cookson, W. R., Murphy, V. and Roper, M. M. (2008). Characterizing the relationships between soil organic matter components and microbial function and composition along a tillage disturbance gradient. *Soil Biology and Biochemistry*, 40: 763-777.
- Ding, G., Liu, X., Herbert, S., Novak, J., Amarasingwardena, D. and Xing, B. (2006). Effect of cover crop management on soil organic matter. *Geoderma*, 130: 229-239.
- Ellerbrock, R. H., Gerke, H. H., Bachmann, J. and Goebel, M. O. (2005). Composition of organic matter fractions for explaining wettability of three forest soils. *Soil Science Society of America Journal*, 69: 57-66.
- Eynard, A., Schumacher, T. E., Lindstrom, M. J., Malo, D. D. and Kohl, R. A. (2006). Effects of aggregate structure and organic C on wettability of Ustolls. *Soil and Tillage Research*, 88: 205-216

Gardening with Plant Probiotics: An Eco-friendly Approach

Richa Salwan, Vivek Sharma and Hitesh Sharma

Soil health and gut health are deeply intertwined. Just as a thriving microbiome is essential for human wellness, fertile, living soil is crucial for producing nutritious, gut-friendly food.

When we talk about probiotics, it refers to beneficial bacteria that keep our gut health and immunity strong. Similarly, in the world of farming, plants beneficial microorganisms are also stepping into the spotlight. As probiotics keeps human body healthy, these plant probiotics acts as secret weapon for keeping plants healthy.

A Tale of Two Worlds: The Gut and the Soil

Probiotics are “live microorganisms which when consumed in sufficient amount exert health benefits”. Similarly, in plants, these microorganisms deploy versatile, complex, multifaceted molecular arsenal to protect hosts and promote growth under diverse stress conditions. As in human gut, probiotics compete with pathogenic bacteria by rapid colonization and adherence with the epithelial cells, plant probiotics residing in soil, around the roots, or inside the plant tissues, actively communicates with the plant. Either gut or plant, the associated microbiome acts as the commander-in-chief and establish as a profound connection between the two ecosystems (human intestines and soil).

Both ecosystems containing trillions of bacteria, fungi, and other microbes that break down organic matter, cycle nutrients, and defend against pathogens. Soil microorganisms have remained as old friends of humans but modern industrial agriculture has severely disrupted this connection. Chemical pesticides and fertilizers destroy soil biodiversity and also reduce the nutrient density of crops. Reduced exposure to natural soil microbes coupled with processed diets has led to lower microbial diversity in the human gut. The decline in both soil and gut health is linked to managing environmental stress such as drought or disease and play role as a protective shield.

Plant probiotics

The term plant probiotic bacteria was proposed by Haas and Keel to categorize a group of microorganisms that benefits plants. Further, Kloepper and Schrot named these beneficial microorganisms as plant growth promoting rhizobacteria (PGPRs). These PGPRs resides in the plant roots-soil interface (rhizosphere). However, some resides in interface (phyllosphere), and some resides in the internal tissues of the plants (endosphere). Based on the location, the plant microbiome is classified as follows:

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Free-living rhizobacteria: These live in the soil immediately surrounding the plant roots (rhizosphere), secreting metabolites that stimulate plant growth and nutrient absorption.

Endophytes: These beneficial microbes live inside plant tissues, such as roots or stems, where they directly exchange nutrients and compounds with the host.

Symbiotic bacteria: These make specialized nodules on roots which fix atmospheric nitrogen for leguminous plants with the best-known example being Rhizobia. For example, Frankia fixes nitrogen by making nodules in Alnus trees.

Beneficial fungi: Fungi like *Trichoderma* are used to enhance nutrient uptake, soil structure, and provide defense against soil-borne pathogens.

Probiotics help plants produce more plant growth regulators and increase chlorophyll content, leading to healthier, with high photosynthesis rate that ultimately increase the crop yield. These plant probiotics also affect the production of flavonoids, organic acids, and other plant metabolites which are useful to human.

Strategies of Plant Probiotics

Similar to probiotics, plant probiotics are in large demand to provide protection from pathogen attack hence enhancing crop resilience by managing biotic and abiotic stress. Despite the structural differences between human epithelial adherence and plant cell wall, the adherence and root colonization, strategies are remarkably similar (Table 1). Four main strategies are as follows:

Direct exclusion (blocking pathogens): Beneficial bacteria like species of *Bacillus* and *Pseudomonas* establish near root surface, or interior plant tissues, physically blocking pathogens from attaching to the plant. Probiotic microbes are highly efficient at rapidly consuming nutrients (carbon, nitrogen, iron) in the root zone, and compete with the pathogens. These plant probiotics produce antagonistic chemical substances, such as antibiotics or bacteriocins that directly inhibit or eliminate nearby pathogens. These also make biofilms on root surfaces, which act as a physical barrier and restrict pathogen movement and access to host.

Chemical warfare (using metabolites): Plant probiotics utilize microbial metabolites to enhance plant growth, increase nutritional quality, and boost stress resistance. The metabolites including organic acids and phytohormones foster healthy root microbiomes and improve soil nutrient availability. Probiotic increases antioxidant production, such as flavonoids and anthocyanins, in crops which improve their nutritional value.

Immune priming (activating resistance): Plant probiotics, including beneficial microbes like *Bacillus* and *Pseudomonas* species, are used in agriculture to prime the plant immune system, a process known as Induced Systemic Resistance (ISR) and protect plants from pathogen attacks.

Growth/Nutrient Boost: Soil often contains insoluble phosphorus and potassium that plants cannot use. Probiotic bacteria like *Bacillus megaterium* and *B. mucilaginosus* produce organic

acids that solubilize the nutrients, making them available for plant uptake. Free-living, associative, or symbiotic bacteria e.g., *Azotobacter*, *Azospirillum*, *Rhizobium* convert atmospheric nitrogen into ammonia, that can be used for growth and chlorophyll production. Probiotics secrete siderophores that bind iron in the soil, making it available to the plant and depriving pathogens of this essential nutrient. Under stress conditions plants produce excessive ethylene, which inhibits root growth. Probiotics breaks down the ethylene precursor by producing 1-Aminocyclopropane-1-carboxylic acid (ACC) deaminase and allows continuous growth of roots under stress conditions.

Table 1: Comparative overview of physiological actions of probiotics in human and plants

Goal	Human	Plant Probiotic
Defense	Enhances phagocytosis and stimulates natural killer T cells to fight infections and even cancer.	Deploys proteases and chitinases to dissolve the cell walls of invading pathogens
Stress relief	Uses the insulin-like pathway to protect cells from oxidative stress.	Induces resistance against environmental “stressors” like drought, salt, and toxins
Growth and Energy	Forms acetate and butyrate like Short-Chain Fatty Acids (SCFAs) to help absorb nutrients.	Secretes growth regulators (like IAA and GA) and siderophores to help roots grab nutrients from the soil
Immune boosting	Improves barrier function and manages allergic or metabolic disorders.	Triggers “Induced Resistance” and primes the plant’s immune system using proteins like Sm1 and epl1

Applications of plant probiotics

Root metabolism: Probiotics specifically improve root metabolism by increasing root biomass and improved nutrient such as nitrogen and phosphorus uptake which results in increased crop yields.

Beneficial bacteria form biofilms on the root surface, creating a protected microenvironment that shields roots from pathogens and helps them better absorb nutrients. Farmers are using strains like *Bacillus subtilis* and *Azospirillum brasilense* to help crops like wheat, corn, and rice grow bigger and healthier.

Environmental stress: Probiotics help the plants in coping with environmental stresses such as high temperature, drought and toxic materials in soil. In drought-prone areas, plant beneficial *B. megaterium* and Mycorrhiza come help plants in absorbing nutrients and water deep in the ground, and hence provide better survival.

Disease management: These microorganisms fight, weaken, or kill pathogens that cause plant diseases. Specifically beneficial microbes like *Pseudomonas putida* and *Trichoderma* spp are applied to young plants (seedlings, flowers, ornamentals) in controlled environments (nurseries/greenhouses) to prevent diseases like root rot, wilt, and blight.

Sustainable Agriculture: The microorganisms like *Bacillus amyloliquefaciens*, *Pseudomonas* and *Trichoderma* produce natural substances including hormones, enzymes and antibiotics that target the cell walls of disease-causing pathogens. Therefore, offer an environment friendly alternative to synthetic pesticides.

Gardening: *Pseudomonas fluorescens* and *Rhizobium* enhance nutrient absorption, root development, and stress resistance. *Rhizobium* boosts nitrogen fixation, while *P. fluorescens* acts as a bio-fungicide that improves soil health. These, along with other

microbes, help plants thrive in suboptimal soil conditions specifically in home gardens.

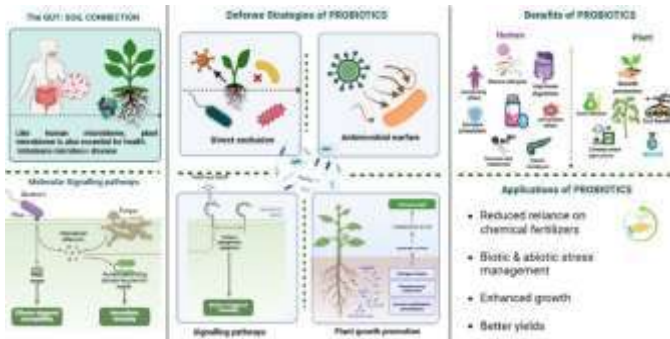


Fig: The revolutionary plant probiotics: Unlocking molecular arsenal for sustainable agriculture

Conclusion

Fertile, living soil acts as a “commander-in-chief” in a system that links human gut health to plant health, acting as an invisible pharmacy for both. Beneficial microbes like *Bacillus* and *Pseudomonas* enhance plant resilience and health by creating a shield against drought, salinity, and disease and also improving nutrient availability (P, N, K, Zn, Fe), antioxidants, and essential oils. By nurturing the soil with these probiotics, the foundation for both sustainable agriculture and human health can be strengthened.

Cotton Cultivation in North India: Package of Practices for Sustainable and Profitable Production

Priyanka Kantwa, Suman Kantwa and Vinod Kantwa

Introduction

Punjab, Haryana, and Rajasthan form the centre of the north-western cotton belt, and cotton (*Gossypium* spp.) continues to be one of the most economically significant fiber crops in North India. According to ICAR-CICR (2023), India is currently the world's greatest producer of cotton, accounting for about 23-25% of worldwide production, with only the northern area producing 18-20% of the country's total. Cotton sustains millions of livelihoods in production, processing, and trading value chains in addition to being an essential raw material for India's quickly growing textile industry. Nonetheless, North India's cotton output is going through a rapid change. Rising temperatures, unpredictable monsoons, whitefly outbreaks, nutrient-depleted soils, and the appearance of pink bollworm (PBW) in Bt cotton fields are all challenges that farmers are facing more and more. These difficulties have led to the necessity for an updated, scientifically supported set of practices that include IPM techniques, high-density planting, climate-smart measures, and digital advising systems.

Cotton classification and its varieties

Gossypium arboreum (Desi cotton), *Gossypium herbaceum* (Levant cotton), *Gossypium hirsutum* (American upland cotton, which occupies 90% of North India), and *Gossypium barbadense* (Egyptian cotton, grown in limited areas) are the four cultivated species that make up the Malvaceae family. Bt cotton (BG-II) still dominates production, according to the most current classification update for 2022-23; however, non-Bt and Desi cultivars are becoming more popular because of their resistance to pink bollworm (PBW). While climate-resilient Desi cultivars like PAU Desi 1 and HD 123 are advised for rainfed or whitefly-prone locations, ICAR-CICR and state agricultural colleges are aggressively promoting High-Density Planting System (HDPS) varieties.

The recommended Bt varieties in Punjab are RCH 773 BG-II and other Bollgard II hybrids, while the non-Bt/Desi options are PAU Bt 2 and PAU Desi 1. In Haryana, the suggested Bt varieties are HD 988 BG-II and Ankur 3028, while the non-Bt/Desi options are H 1098-I and HD 123. In Rajasthan, the recommended Bt varieties are RCH 650 BG-II and JKCH 1050, and the non-Bt/Desi options are RG 559

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and RG 195. In an attempt to increase production and pest resistance in North Indian cotton farming, recent trends show a shift toward short-duration and PBW-tolerant cultivars.

Sowing Time and Seed Rate: Timely planting is crucial for cotton cultivation in order to avoid whitefly and pink bollworm (PBW) infections. The best times to sow vary according on the location. For instance, Punjab and Haryana should plant between April 15 and May 15, but North Rajasthan should plant between April 25 and May 20. When seeding, the soil should be between 18 and 20 degrees Celsius. The recommended seed rate depends on the type of cultivar and planting method. Bt hybrids need 1.5-2.0 kg ha⁻¹ of seed for conventional wider row planting, whereas Desi forms need 12-15 kg ha⁻¹. For compact varieties employed in high-density planting systems (HDPS), the seed rate should be 3-4 kg ha⁻¹ in order to reach a plant density of 90,000-1,10,000 plants per hectare.

Land Preparation: In order to provide enough soil tilth, land preparation for cotton entails one or two cultivations after pre-irrigating the field if necessary. In addition to producing a consistent seedbed, the final land leveling ideally with a laser land leveller also helps cut irrigation water needs by 20-25%.

Nutrient Management: Maintaining square and boll retention in cotton requires balanced nutrition management. It is often advised to apply 150:60:60 kg ha⁻¹ of NPK to Bt cotton in three splits: at sowing (basal), 45 days after sowing (DAS), and during early boll formation. Furthermore, adding 2.5 t ha⁻¹ of

farmyard manure (FYM) enhances the organic matter in the soil. Fertilization and foliar nutrient sprays, such as 1% potassium nitrate (KNO₃) at square formation, 1% magnesium sulfate (MgSO₄) to preserve leaf greenness, and a mixture of 0.5% zinc sulfate (ZnSO₄) and 0.2% boron (B) for micro-nutrient correction, are the focus of emerging methods.

Weed Management: In cotton, controlling weeds is especially important in the first 45 days following seeding. Pendimethalin at 1.0 kg a.i. ha⁻¹ can be used to control pre-emergence. Pyriithiobac sodium or quizalofop ethyl should be used 20-25 days after sowing for post-emergence weed control. Intercultural operations or mechanical weeding can be used to successfully control weeds in the later stages of crop growth.

Irrigation Management: Cotton is particularly vulnerable to moisture stress during blooming and boll production. One irrigation prior to sowing, followed by irrigations every 12 to 15 days during the vegetative stage, is the suggested irrigation schedule. Irrigation should be applied every seven to ten days throughout the crucial flowering to boll formation stage, but it should be avoided once the crop reaches maturity. Water use efficiency (WUE) can be greatly increased by up to 40% by using drip irrigation.

Integrated Pest Management (IPM): The goal of integrated pest management (IPM) in cotton is to reduce the use of chemicals while managing important pests. Yellow sticky traps (8-10 ha⁻¹)

should be set up for whiteflies (*Bemisia tabaci*), and border crops like sorghum or bajra can help lessen infestations. Only when the economic threshold level (ETL) of six adults leaf⁻¹ is attained may insecticides be used. The management of pink bollworm (*Pectinophora gossypiella*) entails synchronized sowing, the use of PBW pheromone traps (five traps per hectare), avoiding long crop periods, and eliminating unopened bolls at harvest to interrupt the pest's life cycle. To keep American bollworm, jassid, and mealybug populations below harmful levels, biocontrol techniques such releasing *Trichogramma*, spraying neem-based formulations, and employing selective insecticides are advised.

Harvesting and Yield: To reduce leaf debris in the harvested cotton, cotton harvesting should start when about 60% of the bolls have opened, ideally early in the morning. Cotton yields in North India normally range from 18 to 22 q ha⁻¹ under standard management techniques. However, PAU and CICR trials have demonstrated that the combination of High-Density Planting System (HDPS), drip irrigation, and Integrated Pest Management (IPM) significantly increases yields, reaching 30 to 35 q ha⁻¹.

Conclusion

Precision agronomy, HDPS, IPM-based pest control, climate-resilient cultivars, and resource-efficient irrigation systems are all necessary for North India's cotton production to be sustainable. Adopting the new set of procedures can lower environmental hazards while greatly increasing farm profitability, production, and fiber quality.

References

- CICR. (2023). Cotton Production Guidelines for North Zone. ICAR-Central Institute for Cotton Research.
- CICR. (2024). Pink Bollworm Management Strategy for Bt Cotton. ICAR-CICR Nagpur Publications.
- PAU. (2023). Package of Practices for *Kharif* Crops. Punjab Agricultural University, Ludhiana. Haryana Agricultural University. (2023). *Cotton Production Handbook*. CCS HAU Hisar.
- Ministry of Agriculture & Farmers Welfare. (2023). *Agricultural Statistics at a Glance*. Government of India.
- FAO. (2022). Global Cotton Production and Market Trends. Food and Agriculture Organization.

Advancing Crop Yield Forecasting Using Drone Imagery and Remote Sensing Technologies

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The rapid advancement of Unmanned Aerial Vehicles (UAVs or drones) and remote sensing technologies is revolutionizing agricultural productivity assessment, particularly in the domain of crop yield monitoring and forecasting. As global agriculture faces increasing pressure from climate variability, resource scarcity, and market volatility, accurate and timely estimation of crop yield has become essential for farmers, policymakers, agribusiness firms, and insurance agencies. Traditional yield estimation methods rely on manual crop cutting experiments, field surveys, and farmer-reported data, which are time-consuming, labor-intensive, and often prone to sampling errors. In contrast, drones integrated with multispectral, hyperspectral, and thermal sensors provide real-time, high-resolution field data that enable precise, large-scale yield monitoring. These technologies support data-driven agricultural planning and reduce uncertainty in production forecasting. By combining drone imagery with vegetation indices, biomass estimation models, and machine learning algorithms, farmers and researchers can generate reliable yield predictions before harvest. This enhances decision-making in harvesting, storage planning, market timing, and risk management. Thus, drone and remote sensing techn-

ologies are becoming foundational tools for intelligent, predictive, and sustainable crop yield monitoring systems.

Applications in Crop Yield Monitoring

Biomass and Canopy Analysis for Yield Prediction:

Drone-mounted multispectral and hyperspectral cameras capture detailed canopy reflectance data. Vegetation indices such as: NDVI (Normalized Difference Vegetation Index) EVI (Enhanced Vegetation Index) SAVI (Soil Adjusted Vegetation Index) are used to estimate plant vigor, chlorophyll content, and biomass accumulation. Since biomass growth is strongly correlated with final yield, these indices help generate early-season yield predictions. By monitoring crop development stages, farmers can adjust fertilizer application or irrigation to optimize final production.

Growth Stage Monitoring Remote sensing enables continuous monitoring of crop phenological stages such as:

Germination Vegetative growth Flowering Grain filling Maturity Abnormalities in crop growth patterns can be detected early. If crop development lags due to nutrient deficiency or water stress, corrective measures can be applied to prevent yield loss. Timely monitoring ensures that crop yield potential is preserved throughout the season.

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Stress Detection and Yield loss Prevention:

Thermal sensors mounted on drones detect temperature variations in crop canopies, indicating water stress. Similarly, multispectral imaging identifies: Nutrient deficiencies Pest infestation Disease outbreaks early detection prevents large-scale yield reductions. By applying targeted interventions, farmers can maintain uniform crop health and maximize yield.

Precision Fertilizer and Irrigation Optimization:

Remote sensing data helps identify spatial variability within fields. Instead of uniform fertilizer application, farmers can adopt variable rate technology (VRT) to apply inputs based on crop needs. Optimized irrigation scheduling using thermal and soil moisture mapping prevents over-irrigation or drought stress, both of which significantly affect yield quantity and quality. Efficient resource allocation directly contributes to improved yield outcomes.

Yield Mapping and Spatial Variability Analysis:

High-resolution drone imagery generates yield variability maps within fields. These maps help: Identify high-yield and low-yield zones Understand soil productivity differences Plan future crop rotations Improve land management strategies Yield mapping supports long-term precision farming practices and enhances farm profitability.

Pre-Harvest Yield Estimation: Drone-based crop height measurement, canopy density analysis, and biomass modeling are integrated with statistical and machine learning models to forecast yields before

harvest. Pre-harvest yield estimation benefits: Farmers (harvest planning) Agribusiness firms (procurement strategy) Governments (food security planning) Insurance agencies (risk assessment). This reduces market uncertainty and improves supply chain efficiency.

Post-Disaster Yield Assessment: After natural calamities such as floods, droughts, cyclones, or hailstorms, drones conduct rapid aerial surveys to quantify yield damage. These objective assessments support: Accurate crop insurance claims Government compensation programs Disaster relief planning Drone-based yield loss assessment ensures transparency and faster claim settlements.

Advantages of Drone and Remote Sensing in Crop Yield Monitoring

High Accuracy in Yield Prediction: Advanced imaging sensors combined with predictive modeling significantly enhance yield estimation precision compared to traditional survey methods.

Time Efficiency: Large agricultural fields can be surveyed within minutes, enabling rapid yield assessment across extensive areas.

Reduced Sampling Errors: Unlike manual crop cutting experiments, drone data covers the entire field, minimizing sampling bias.

Early Decision Support: Pre-harvest yield forecasts allow farmers to plan marketing strategies, storage facilities, and labor requirements in advance.

Support for Precision Agriculture: Integration with GIS, IoT, and AI-based analytics strengthens smart farming systems and long-term yield optimization.

tion.

Challenges in Crop Yield Monitoring Using Drones

High Initial Investment: Acquiring drones equipped with advanced sensors and data processing software requires significant capital investment.

Need for Technical Expertise: Processing remote sensing data and interpreting yield models require skilled personnel, which may be limited in rural areas.

Regulatory Restrictions: Drone flight permissions, airspace regulations, and licensing norms may delay operational use in certain regions.

Data Processing and Connectivity Issues: Poor internet connectivity in rural regions affects real-time data transfer and cloud-based analysis.

Weather Dependency: Drone operations are influenced by weather conditions such as wind, rainfall, and cloud cover.

Future Directions in Crop Yield Monitoring

Integration with Artificial Intelligence (AI): Machine learning and deep learning models will enhance yield prediction accuracy by analyzing multi-temporal drone data.

IoT and Sensor Networks: Integration with ground-based IoT soil sensors will improve real-time yield forecasting.

Big Data Analytics: Combining satellite data, historical yield records, and drone imagery will enable large-scale regional production forecasting.

Low-Cost and Rental Models: Development of affordable drones and cooperative rental systems

will make yield monitoring accessible to smallholder farmers.

Digital Agriculture and Smart Insurance: Drone-based yield assessment will strengthen digital crop insurance systems, reducing claim processing time and increasing transparency.

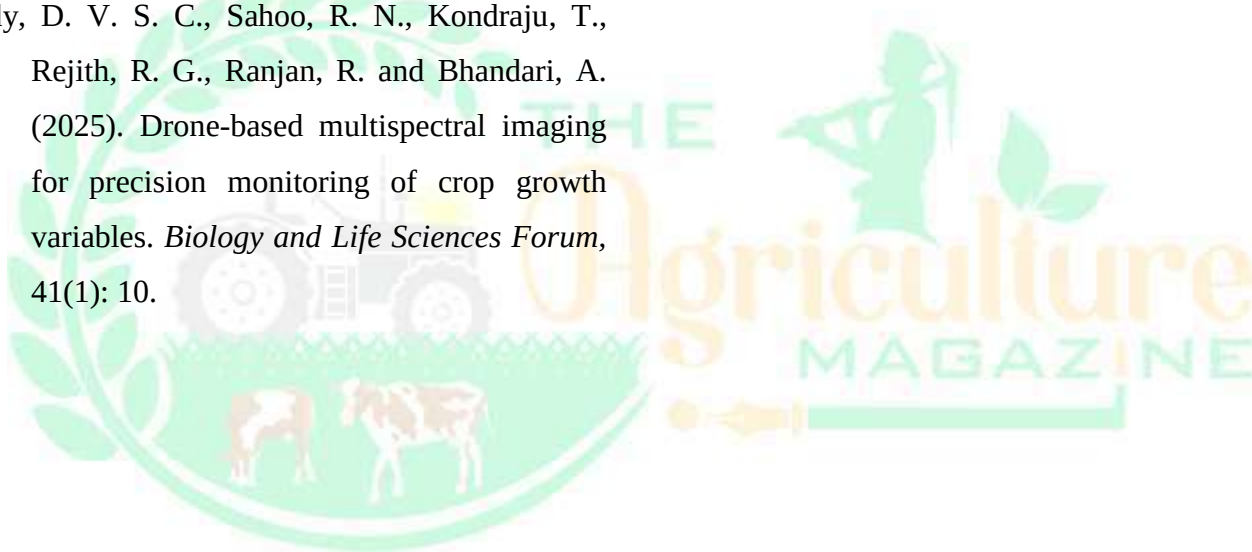
Conclusion

Drone and remote sensing technologies are transforming crop yield monitoring by providing precise, timely, and scalable data solutions. These technologies minimize reliance on manual field surveys, enhance forecasting accuracy, and support precision agriculture. With supportive policies, affordable technological models, and capacity-building initiatives, drone-based yield monitoring can significantly improve farm productivity, income stability, and climate resilience. In the coming years, drones will evolve from simple monitoring tools into integrated smart farming systems that drive data-based agricultural planning and sustainable crop production at both national and global levels.

References

- Hunt, E. R. and Daughtry, C. S. T. (2018). What good are unmanned aircraft systems for agricultural remote sensing and precision agriculture? *International Journal of Remote Sensing*, 39(15-16): 5345-5376.
- Miller, J. O., Mondal, P. and Sarupria, M. (2024). Sensor-based measurements of NDVI in small grain and corn fields by tractor, drone, and satellite platforms. *Crop and Environment*, 3(1): 33-42.

- Bassine, F. Z., Epule, T. E., Kechchour, A. and Chehbouni, A. (2023). Recent applications of machine learning, remote sensing, and IoT approaches in crop yield prediction: A critical review. *arXiv Preprint*. <https://arxiv.org/abs/2306.04566>
- Moghimi, A., Yang, C. and Anderson, J. A. (2019). Aerial hyperspectral imagery and deep neural networks for high-throughput yield phenotyping in wheat. *Computers and Electronics in Agriculture*, 162: 102-110.
- Reddy, D. V. S. C., Sahoo, R. N., Kondraju, T., Rejith, R. G., Ranjan, R. and Bhandari, A. (2025). Drone-based multispectral imaging for precision monitoring of crop growth variables. *Biology and Life Sciences Forum*, 41(1): 10.



Macadamia Nuts: Composition, Health Effects and Dietary Importance

Shilpa, Priyanka Thakur, Simran Kashyap, Rimpika and Ankita Sood

Introduction

Macadamia nut is widely regarded as one of the finest edible nuts in the world and is known by several common names such as Queensland nut, Australian nut, Bopple nut, Bauple nut, Popple nut, Kindal, Boombera and Burrawang (Hardner *et al.*, 2005). Among the different species, *Macadamia integrifolia* is considered a relatively recent addition to the group of cultivated crop plants worldwide. It holds particular importance because it is the first and only native food plant of Australia that has successfully been developed into a commercial crop. Although the plant originated in Australia, significant commercial development of macadamia cultivation has taken place in Hawaii over the past six decades, where improved production techniques and processing technologies have been established (Sharma *et al.*, 2015). In recent years, macadamia cultivation has also gained attention in India due to



its high economic value and increasing demand in domestic as well as international markets. The crop is considered suitable for regions with warm and humid climates, particularly in parts of the northeastern states such as Arunachal Pradesh, Nagaland, Meghalaya and Assam, where climatic conditions resemble those of its native habitat. Efforts have been made by agricultural research institutions and government agencies to introduce and promote macadamia as a potential high-value nut crop for diversification of horticulture in these regions. Although commercial cultivation in India is still at an early stage, the crop shows promising potential due to favourable agro-climatic conditions and increasing interest among farmers and entrepreneurs.

Macadamia nuts are widely regarded as one of the most delicious edible nuts in the world. They are relatively small in size but are valued for their rich, buttery flavour and crisp texture. In addition to their pleasant taste, macadamia nuts are nutritionally

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Table 1: Nutritive value of the Macadamia nut

Nutrient	Value	Nutrient	Value	Nutrient	Value
Energy	718 Kcal	Pyridoxine	0.275 mg	Manganese	4.131 mg
Carbohydrates	13.82 g	Riboflavin	0.162 mg	Phosphorus	188 mg
Protein	7.91 g	Thiamine	1.195 mg	Selenium	3.6 mcg
Total Fat	75.77 g	Vitamin A	0 IU	Zinc	1.30 mg
Cholesterol	0 mg	Vitamin C	1.2 mg	Sodium	5 mg
Dietary Fiber	8.6 g	Vitamin E	0.24 mg	Potassium	368 mg
Folates	11 mcg	Calcium	85 mg	Phyto-sterols	116 mcg
Niacin	2.473 mg	Copper	0.756 mg	β-sitosterol	108 mcg
Pantothenic acid	0.758 mg	Iron	3.69 mg		

Source: USDA National Nutrient data base (www.nutritionandyou.com)

important as they provide a good source of proteins, healthy fats and essential minerals. These nuts possess a naturally sweet taste and can be consumed in various forms, such as raw directly from the shell, dry roasted or cooked in oil. Macadamia nuts are considered a high-energy food due to their significant oil and nutrient content. Because of their distinctive flavour and texture, they are commonly used in a variety of culinary preparations. They are frequently incorporated into bakery products such as cakes and pastries, confectionery items, ice cream, salads, roasted dishes and casseroles to enhance both flavour and nutritional value. Nutritive value of macadamia nut has been presented in the Table 1.

From a nutritional perspective, macadamia nuts are particularly notable because they are among the few natural food sources that contain palmitoleic acid, a beneficial monounsaturated fatty acid. This fatty acid is also present in relatively higher concentrations in the human liver. Palmitoleic acid has been associated with several health benefits, including improved insulin sensitivity and reduced inflammation. It may also help protect pancreatic beta cells, which are responsible for insulin secretion, thereby supporting metabolic health.

Nutritional Value and Culinary Uses: Macadamia nuts are widely considered one of the most delicious and nutritionally valuable edible nuts in the world. Although small in size, they are well known for their rich, buttery flavour and crisp texture. In addition to their appealing taste, macadamia nuts provide important nutrients such as proteins, essential minerals and beneficial fatty acids. These nuts have a naturally sweet taste and can be consumed in several forms, including raw directly from the shell, dry roasted or cooked in oil. Due to their distinctive flavour and texture, macadamia nuts are commonly used in various food preparations. They are frequently incorporated into bakery products such as cakes and pastries, confectionery items, ice creams, salads, roasted dishes and casseroles. Their inclusion in these foods enhances both the taste and the nutritional quality of the final product.

Health Benefits of macadamia nut

Low in fats: Macadamia nuts contain a wide range of beneficial fats that contribute to a balanced and healthy diet. Among all edible nuts, they possess one of the highest concentrations of monounsaturated fatty acids (MUFAs), particularly in the form of Omega-9 and Omega-7 fatty acids. Omega-9 fatty

acids are known for their potential health benefits, including reducing inflammation, improving cardiovascular function and lowering levels of low-density lipoprotein (LDL), commonly referred to as “bad cholesterol.” These effects collectively support better heart health and overall well-being.



In addition, macadamia nuts contain Omega-7 fatty acids, which are relatively uncommon in most food sources. Emerging scientific studies suggest that Omega-7 may play an important role in metabolic health by helping regulate blood glucose levels and improving insulin response. Besides monounsaturated fats, macadamia nuts also provide polyunsaturated fatty acids (PUFAs), including Omega-3 and Omega-6 fatty acids. Although both of these fatty acids are essential for human health, modern diets often contain excessive amounts of Omega-6 relative to Omega-3. Macadamia nuts offer a favourable fatty acid composition, with an approximate ratio of 6:1 of Omega-6 to Omega-3, which is considered beneficial for maintaining optimal physiological balance and supporting overall health.

Low in carbohydrates: Macadamia nuts contain relatively low levels of carbohydrates and high amounts of unsaturated fats, making them a suitable snack for individuals who aim to maintain stable blood sugar levels. Due to their nutritional composi-

tion, consumption of macadamia nuts results in only a minimal increase in post-prandial blood glucose levels. This characteristic makes them particularly beneficial for people who are concerned about glycemic control. Recent preliminary studies indicate that including macadamia nuts as part of a carbohydrate-rich meal or snack may help moderate the rise in blood glucose levels after eating. This effect is especially important for individuals who follow dietary approaches such as low-carbohydrate, high-fat (LCHF) diets or for those managing conditions like diabetes. The growing use of personal continuous glucose monitoring devices has further increased awareness and discussion regarding the importance of maintaining stable blood sugar levels through dietary choices. Macadamia nuts, with their favorable nutrient profile, may therefore play a supportive role in blood glucose management and metabolic health.

Macadamia oil benefits: Macadamia oil extracted from the kernels of macadamia nuts (*Macadamia integrifolia* and *Macadamia tetraphylla*), is a light, pale yellow oil renowned for its rich content of monounsaturated fats, particularly oleic acid (Omega-9) and palmitoleic acid (Omega-7). These fatty acids make up approximately 70-80% of the oil's composition, contributing to its stability, mild buttery flavor, and notable health benefits. The oil has a high smoke point of around 210-230°C (410-450°F), which makes it suitable for medium-heat cooking methods such as sautéing, roasting, and frying without breaking down into harmful compo-

Table 1: Comparison of macadamia nut with other nut tree crops

Nutritional Component	Macadamia	Almond	Brazil Nut	Cashew	Hazelnut	Walnut	Pecan nut	Pistachio
Serving* (number of nuts)	10	23	6	18	21	7	19	49
Calories	204	164	187	157	178	185	196	159
Total Fat (g)	22	14	19	12	17	19	20	13
Saturated Fat (g)	3.4	1	5	2	1.3	1.7	2	1.7
Polyunsaturated Fat (g)	0.4	3.5	6.9	2.2	2.2	13.4	6	4
Omega-6 (g)	0.4	3.5	6.8	2.2	2.2	10.8	5.8	4
Omega-3 (g)	0.06	0.01	0.01	0.02	0.03	2.57	0.28	0.08
Omega-6: Omega-3	6:1	246:1	664:1	125:1	90:1	4:1	21:1	48:1
Monounsaturated Fat (g)	17	9	7	7	13	3	12	7
Omega-7 (g)	3.69	0.07	0.06	0.04	0.03	0	0	0.14
Omega-9 (g)	12.4	8.9	6.7	6.7	12.9	2.5	11.5	6.4
Carbohydrates (g)	4	6	3	9	5	4	4	8
Sugar (g)	1	1	1	2	1	1	1	2
Fiber (g)	2.4	4	2	1	2.8	2	2.7	3
Net Carbs (g)	1.5	3	1	8	2	2	1.2	5

Source: USDA nutrient database

unds. Nutritionally, macadamia oil supports cardiovascular health by lowering LDL cholesterol and raising HDL cholesterol, while the palmitoleic acid it contains offers anti-inflammatory effects and may improve insulin sensitivity. Beyond its culinary uses, macadamia oil is valued in the cosmetic industry for its moisturizing properties and similarity to natural skin lipids, making it a popular ingredient in skincare and haircare products. Its light texture and mild aroma allow it to absorb quickly into the skin without clogging pores, enhancing its appeal for use in lotions, massage oils, and other personal care items. Overall, macadamia oil is a versatile product prized for its nutritional, culinary, and cosmetic applications.

Anti-Inflammatory benefits: Inflammation is an important health concern and represents a complex response of the immune system to injury, infection or other harmful stimuli. Although inflammation is a natural protective mechanism, excessive or prolonged inflammatory responses can contribute to

the development of various chronic diseases. Dietary factors play a major role in influencing inflammation levels in the body. High consumption of added sugars and excessive intake of saturated fats, commonly found in certain meat and dairy products, are known to promote inflammatory processes.

Macadamia nuts may help in reducing inflammation due to their rich content of beneficial fats and other bioactive compounds. They contain a high proportion of unsaturated fatty acids, including a favorable balance of Omega-3 and Omega-6 fatty acids, which are associated with anti-inflammatory effects. In addition, macadamia nuts provide essential vitamins, minerals and phytonutrients that contribute to overall health. Regular consumption of macadamia nuts may therefore support the reduction of inflammation and promote better health, particularly in relation to digestive function, cardiovascular health and brain function.

Role in Blood Sugar Regulation: Macadamia nuts contain relatively low levels of carbohydrates and

high levels of unsaturated fats, making them a suitable snack option for individuals aiming to maintain stable blood glucose levels. Their consumption generally results in only a minimal rise in post-meal blood sugar levels. Preliminary research suggests that including macadamia nuts in carbohydrate-rich meals or snacks may help moderate the increase in blood glucose levels following consumption. This property is particularly beneficial for individuals following low-carbohydrate, high-fat (LCHF) diets or those managing metabolic conditions such as diabetes. With the increasing use of continuous glucose monitoring devices, greater attention has been directed toward dietary choices that support effective blood sugar management.

Macadamia nuts are widely regarded as a premium category among tree nuts because of their superior nutritional composition and rich, creamy texture. They contain one of the highest levels of monounsaturated fatty acids among edible nuts, which are known to support heart health and improve lipid balance. While some other tree nuts may provide greater amounts of protein, macadamia nuts are particularly valued for their ability to deliver long-lasting energy through their high content of healthy fats. Their smooth taste and nutritional benefits make them a highly desirable nut in both dietary and culinary applications. The increasing demand for macadamia nuts reflects their reputation as a high-quality nut variety with significant health and nutritional advantages compared with many other commonly consumed nuts.

Conclusion

Macadamia nuts are widely recognized as one of the most nutritionally valuable and premium edible nuts due to their unique composition and health-promoting properties. They are rich in monounsaturated fatty acids, particularly oleic acid (Omega-9) and palmitoleic acid (Omega-7), which contribute significantly to cardiovascular health, improved lipid profiles and reduced inflammation. In addition, macadamia nuts provide essential nutrients such as dietary fiber, proteins, vitamins and minerals that support overall physiological functions. Their relatively low carbohydrate content and favorable fatty acid composition make them suitable for individuals aiming to maintain stable blood glucose levels and metabolic health. Besides their nutritional importance, macadamia nuts have diverse culinary applications and are widely used in bakery products, confectionery items and salads due to their pleasant buttery flavor and crisp texture. The oil extracted from macadamia kernels also possesses considerable nutritional and cosmetic value. Therefore, macadamia nut cultivation and consumption have great potential for promoting both human health and agricultural diversification.

References

- Hardner, C. M., Peace, C. P. Henshall, J. and Manners, J. (2005). Opportunities and constraints for marker assisted selection in Macadamia breeding. *Acta Horticulturae*, 694: 85-90.
- Sharma, G., Yadav, A., Sharma, D. P. and Sharma N.

(2015). Macadamia nut. In: Temperate Fruit Crop Breeding: Domestication to Cultivar Development (Part I and Part II), Editors: S. N. Ghosh, M. K. Verma and A. Thakur, Jaya Publishing House, 27B, Pocket B, Dilshad Garden, Delhi 110095. Pp: 351380.

USDA Food Data Central. 2023. U.S. Department of Agriculture, Agricultural Research Service. Available at: <https://fdc.nal.usda.gov>.



Heavy Metals in Soil: A Hidden Threat to Soil Health and Food Safety

M. A. Ajabe and N. M. Maske

Abstract

Heavy metals in soil have become an increasing environmental concern due to their persistence, toxicity and ability to accumulate in plants and food chains. These metals, including lead (Pb), cadmium (Cd), arsenic (As), mercury (Hg) and chromium (Cr), originate from both natural and human induced activities such as industrial emissions, mining, excessive use of fertilizers, pesticides and sewage sludge application. Unlike organic pollutants, heavy metals do not degrade and remain in soil for long periods, affecting soil fertility, microbial activity and crop productivity. Their accumulation in agricultural soils poses serious risks to plant growth, human health and ecosystem stability. Understanding the sources, impacts and management of heavy metal contamination in soils is essential for maintaining soil health and ensuring safe agricultural production.

Introduction

Soil is a vital natural resource that supports plant growth, regulates water and sustains diverse biological communities. However, increasing industrialization, urbanization and intensive agricultural practices have led to contamination of soils with heavy metals. Heavy metals are elements with relatively high atomic weight and density that can be toxic to plants, animals and humans even at low concentrations. Common heavy metals found in contaminated soils include lead (Pb), cadmium (Cd), arsenic (As), mercury (Hg), nickel (Ni), chromium (Cr) and copper (Cu). While some metals such as zinc (Zn), copper (Cu) and iron (Fe) are essential micronutrients for plant growth, their excessive concentrations can become toxic.

Heavy metal contamination affects soil physical, chemical and biological properties and may lead to reduced crop productivity and environmental degradation. Therefore, understanding the behaviour of heavy metals in soil and adopting appropriate management strategies is crucial for sustainable agriculture and environmental protection.



Fig. 1. Heavy Metals in Agricultural Soils: Sources, Influencing Factors, and Remediation Strategies

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Content of Topic

Heavy Metals in Soil

Heavy metals are naturally present in soils as components of parent rock material. However, their concentrations can increase significantly due to anthropogenic activities. Unlike many other pollutants, heavy metals are non-biodegradable and persist in soils for long periods. They accumulate in the soil profile and may enter the food chain through plant uptake, posing risks to human and animal health.

Sources of Heavy Metals in Soil

Heavy metal contamination in soils may arise from both natural and human-induced sources.

Natural Sources

- ✓ Weathering of parent rocks and minerals
- ✓ Volcanic eruptions and natural geological processes

Anthropogenic Sources

- ✓ Industrial effluents and mining activities
- ✓ Excessive use of chemical fertilizers and pesticides
- ✓ Application of sewage sludge and wastewater irrigation
- ✓ Atmospheric deposition from vehicles and industries

These activities increase the concentration of heavy metals in soils, especially in urban and peri-urban agricultural areas.

Effects of Heavy Metals on Soil and Plants

High concentrations of heavy metals negatively affect soil quality and plant growth. They can

disturb soil microbial communities, inhibit enzymatic activities and reduce nutrient cycling. In plants, heavy metal toxicity may lead to:

- ✓ Reduced seed germination
- ✓ Stunted root and shoot growth
- ✓ Chlorosis and leaf necrosis
- ✓ Decreased crop yield and quality

Some metals can accumulate in edible plant parts, making food unsafe for consumption.

Impact on Human Health and Environment

Heavy metals entering the food chain can cause serious health problems in humans and animals. Long-term exposure to contaminated food or water may result in neurological disorders, kidney damage, cancer and other chronic diseases. In addition to health risks, heavy metal contamination affects biodiversity, reduces soil fertility and disturbs ecological balance.

Management and Remediation of Heavy Metal Contaminated Soils

Managing heavy metal contamination requires integrated approaches to reduce their mobility and toxicity in soil.

Phytoremediation: Using plants that can absorb or accumulate heavy metals from soil.

Soil Amendments: Application of organic matter, biochar and lime to immobilize heavy metals.

Proper Waste Management: Treating industrial effluents and sewage before disposal or irrigation.

Balanced Fertilization: Avoiding excessive use of chemical fertilizers and pesticides.

Regular Soil Testing: Monitoring heavy metal

levels in agricultural soils to ensure safe crop production.

These practices help reduce contamination and improve soil quality.

Conclusion

Heavy metals in soil represent a serious environmental challenge affecting soil health, agricultural productivity and food safety. Their persistence and toxicity make them difficult to remove once they accumulate in soils. Sustainable soil management practices, strict environmental regulations and increased awareness among farmers and industries are essential to prevent and control heavy metal contamination. Protecting soil from such pollutants is crucial for maintaining ecosystem balance, ensuring safe food production and safeguarding human health for future generations.

References

- Brady, N. C. and Weil, R. R. (2017). *The Nature and Properties of Soils* (15th ed.). Pearson Education.
- Alloway, B. J. (2013). *Heavy Metals in Soils: Trace Metals and Metalloids in Soils and their Bioavailability*. Springer, Dordrecht.
- Kabata-Pendias, A. (2011). *Trace Elements in Soils and Plants* (4th ed.). CRC Press.
- FAO. (2018). *Assessment of Soil Pollution: A Global Perspective*. Food and Agriculture Organization of the United Nations, Rome.

Sprouting Broccoli: A Nutrient Dense Cole Crop

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Introduction

Sprouting Broccoli (*Brassica Oleracea* var. *Italica* L.) is commonly known as Broccoli. It is one of the most important cool season vegetable crop belonging to Brassicaceae family. It belongs to cole group, which constitute large group of temperate vegetables they require low temperature for proper growth and development. Among the cole crops, it is richest source of nutrients viz., Vitamin A (9000 mg/100 g), Vitamin C (137 mg/100 g) and Iron (205 mg/100 g), and minerals like phosphorus, calcium and potassium etc. It is consumed as salad, and in sauted form as well as fried vegetable. It has antioxidant properties due to presence of sulphoraphane.



Soil and Climatic Requirement: The crop thrives well in fertile sandy loam soil rich in organic matter having good drainage facility with a pH range of 6-7. It is most important cool season crop grown during winter months. In hills, it can be grown as spring-summer crop. Generally, good seed germination is observed at a temperature range between 18-22°C.

The optimum temperature required 12-18°C for proper growth and development. Crop growth and development is adversely affected, if temperature goes beyond 25°C.

Manure and Fertilizers: Incorporate 200-250 q ha⁻¹ well decomposed farm yard manure as basal dose. Whereas, half of the nitrogen along with full dose of phosphorus and potassium is applied at the time of field preparation on the other hand, remaining dose of nitrogen was top dressed in two to three splitting through broadcasting method. Generally, a dose of 80-100 kg ha⁻¹ Nitrogen, 50-60 kg ha⁻¹ Phosphorus and 50-60 kg ha⁻¹ Potassium was given during the whole cropping period. Foliar spray of urea @ 1-1.5% was also found beneficial for better growth and development of the crop.

Nursery Management: Nursery raising is the one of the most important criteria, which decides the crop performance after transplanting the seedlings in the main field. It is important place where the seedlings are grown under the favourable conditions until the seedlings not becomes ready for transplanting the main field. Generally, the site selected for nursery raising should be well drained and organic matter rich soil which provides better conditions for seedling growth. Generally, 250-400 g seeds are sufficient to raise the seedlings for one hectare area. The seeds were sown in pro-trays during the August-

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September and the seedlings becomes ready for transplanting within 25-30 days depending upon the prevailing weather conditions.

Transplanting: The seedlings becomes ready for transplanting in 25-30 days after sowing when the seedlings, possess five to six true leaves. A healthy and vigorous seedling should be selected for transplanting. The seedlings were transplanted at a distance of 65×45 cm. A light irrigation should be given to the seedlings just after the transplanting. One day prior to transplanting operation, the seedlings should be irrigated in well advance for easy uprooting of the seedlings in order to avoid root damage.



Harvesting and Yield: The crop becomes ready for harvesting in 60-70 days after transplanting. The tender branches consisting of small heads are cut along with few leaves and stem portion with the help of sharp sickle. Harvesting is done at an interval of 30-40 days. The yield varies from 100-200 q ha⁻¹ depending upon the variety and management operations.

Mutation: A Breeding Method for Improvement in Vegetable Crops

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Abstract

Global food security is threatened by population growth, requiring a 70 % increase in food production by 2050. Improving crop varieties through genetic diversification is crucial. Mutation breeding using physical (e.g., gamma rays) or chemical (e.g., EMS) mutagens is a key technique for inducing genetic variation. This method helps develop crops with improved traits like yield, climate adaptability, nutrient content and input efficiency. Over 3,362 mutant varieties have been developed, predominantly using physical mutagens. Mutation breeding has been successfully applied to cereals, legumes, oilseeds and other crops. It enhances both qualitative and quantitative traits. This technique is essential for creating resilient and productive crops to meet future food demands. Combining mutation breeding with other techniques is a promising approach. Continued research and development in mutation breeding are vital for global food security.

Introduction

In plant breeding, a variety of techniques can be employed to enhance a crop's genetic variability, which is followed by selection processes that look for beneficial genotypes (those exhibiting increased yield, disease resistance or improved flower color). Cross-breeding is one of the primary techniques used by plant breeders to try to integrate advantageous traits from various sources into a single genotype. Conversely, mutation breeding exploits the potential for gene modification through the application of chemical or physical mutagens to seeds or other plant parts. "Mutation" was first used by Dutch botanist Hugo De Vries (1848-1935). According to him any

abrupt, heritable alteration to an organism's DNA that is not caused by regular recombination and segregation is called a mutation. It refers to any modifications made to an organism's DNA that are not brought about by recombination and segregation brought on by hybridization. Mutation breeding is frequently employed to give crops new and desirable features. Its primary goal is to cause a great deal of variety in the population. The degree of genetic variability found in the available germplasm is the basis for choosing superior germplasm. In certain minor vegetable crops such as leafy (basella, palak, spinach and amaranth), broccoli, brussels sprouts, chinese cabbage and tubers like elephant foot yam

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and chinese potatoes. There is very little genetic variability. According to Ashadevi *et al.*, (2017) induced mutagenesis can be effectively used in these situations as a substitute to create variability in many quantitative aspects. Because mutation breeding involves modifying the genetic material of an already-adopted cultivar to make corrections. It also aids in accelerating the development of variations. A limited number of experiments successfully resulted in the release of new varieties in crops such as tomato and okra. Like spontaneous genetic events, these intentionally produced genetic events are diverse and can be classified as either chromosome aberrations (involving a few or many genes) or gene mutations (involving only one gene). The plant breeder is typically more interested in the recessive gene mutations as opposed to chromosome abnormalities which frequently result in decreased fertility-a major disadvantage for species that are spread by seeds. Chemicals like EMS (ethyl methane-sulphonate) or different forms of ionizing radiation (such as X-rays, neutrons, ultraviolet light, *etc.*) can cause mutations. Vegetatively propagated crops are an ideal group of plants for the use of mutant breeding techniques for a number of reasons. The main advantage of mutation induction in vegetatively propagated crops is the ability to change one or a few characters of an otherwise out-standing cultivar without altering the remaining and often unique part of the genotype. The sole cause of variation in obligatory apomicts or sterile plants is mutation.

Characteristics of Mutation

Below is a summary of the primary characteristics of mutations:

- ✓ A mutation can happen at any point throughout an organism's development.
- ✓ While the majority of mutations are detrimental to the organism, a tiny percentage (0.1 %) may be helpful for crop improvement.
- ✓ Although dominant mutations sometimes occur, recessive mutations are the norm.
- ✓ Both germinal and somatic cells are susceptible to mutation.
- ✓ Both big and tiny mutations are possible.
- ✓ Any gene is susceptible to mutation.
- ✓ Natural factors or artificial induction can cause mutations.
- ✓ Mutations can happen again and again because they are recurrent.
- ✓ Both forward and backward mutations can take place.
- ✓ The majority of mutant alleles exhibit pleiotropy.

Limitations

- ✓ Low-frequency.
- ✓ A lot of populations must be screened.
- ✓ Only one or two characters can be improved.
- ✓ The majority of mutations are harmful.
- ✓ Micro mutation identification is quite challenging.
- ✓ Following mutation treatment, there is a limited induction of economically significant mutants.

Mutagens

The term “mutagens” refers to substances that alter DNA. Physical and chemical mutagens are

the two categories into which they are divided according to their nature. They produce new traits and increase the genetic diversity of plants by causing genes to mutate at rates higher than the spontaneous background (Lagoda, 2007). The two most often utilized physical and chemical mutagens in crop improvement programs are gamma radiation (Muralitharan and Rajendran, 2011; Ashadevi *et al.*, 2017) and ethylene methane sulfonate (EMS) (Jabeen and Mirza, 2002; Sheeba *et al.*, 2005; Jayakumar and Selvaraj, 2003; Karthika and Lakshmi, 2006; Kojjagar *et al.*, 2011).

Physical Mutagens: Several kinds of radiation are among these mutagens. The mutagenic agent known to affect genes is radiation which was originally identified in 1920. However, Roentgen discovered X-rays in 1895, while radiation itself was identified in 1890. Marie and Pierre Curie discovered the radioactive element in 1898, whereas Becquerel created radioactivity in 1896. Both ionizing and non-ionizing radiations are part of the physical mutagen. The DNA's double helix structure is broken by ionizing radiation. X-rays, gamma rays and neutrons are among the frequently employed radiation types. Ionizing gamma rays are the most often utilized physical mutagens (Ashadevi *et al.*, 2017). According to Jadhav *et al.* (2012), these are electromagnetic radiations that behave physically and affect living things similarly to X-rays. Ionizing radiation is preferred because of its high penetration, high mutagenesis frequency, convenience of usage and lack of disposal issues (Gupta, 2019).

The cellular repair mechanism joins the damaged DNA fragments after they have occurred. These DNA repair systems are only able to withstand low radiation levels and when exposure to ionizing radiation increases, the organism's genome undergoes irreversible alterations that build up over time. By deleting nucleotides, it alters the DNA sequence, resulting in defective transcripts, reading frame shifts or inactive protein products (Anon., 2019).

Chemical Mutagens: A variety of chemical mutations that can permanently alter the bases of DNA have been found as a result of efforts to prevent aberrations brought on by ionizing radiation and negative impacts. Ethyl Methane is one of the chemical mutagens in addition to MMS, sodium azide and mustard gas, sulphonate ($\text{CH}_3\text{SO}_2\text{OC}_2\text{H}_5$) is utilized to induce variability (Jayakumar and Selvaraj, 2003; Ashadevi *et al.*, 2017). Chemically generated mutations are commonly used due to their ease of usage in contrast to irradiation treatment. They also don't need any special tools and as the frequency of mutations rises, point mutations, single base pair alterations and single nucleotide polymorphisms are produced. Seeds and in vitro grown tissues of different plants such as corms, rhizomes, bulbs, tubers, vegetative propagules, *etc.*, are subjected to chemical mutagenic treatments (Suprasna *et al.*, 2012b; Xu *et al.*, 2012). The DNA replication machinery recognizes and modifies guanine and cytosine as adenine or cytosine respectively, when ethyl methane sulphonate adds an

ethyl group to them. A nonsense codon that prevents transcription may arise from this base shifting, which also alters the mRNA and amino acid sequence during protein synthesis, giving mutant plants a different protein (Anon., 2019).

Mutagen Parameters

Mutations can be harmful in nature. In addition to mutation frequency, mutagenic efficiency and the efficacy of a specific mutagen dose. It is crucial to understand specific mutagen characteristics during a mutation experiment, such as the lethal dose-50 (LD₅₀) dose of a given mutagen. The amount of radiation or chemical mutagen needed to kill 50 % of the treated plants is known as the LD₅₀. It is useful for figuring out the effective dosage that produces more mutations while lowering mortality. The percentage of altered plants in the overall population following exposure to a mutagenic agent is known as the mutation frequency. To regain a high frequency of beneficial mutations it is crucial to investigate the mutagenic efficiency and effectiveness of a certain mutagen (Kumar and Mani, 1997). Certain high dosages of mutagenic therapies exhibit greater mutation frequency, mortality, damage and sterility while, certain lower doses exhibit significantly higher mutation frequency and less of these effects. Since changes are desirable in mutation breeding programs when they are free from undesired genetic alteration only, mutagenic therapies that induce a high mutation rate with less damage and adverse effects are generally greatly sought for. Mutagenic efficiency is the amount of

genetic damage brought about by a mutagen dose in relation to the total biological damage in the first mutated (M₁) generation, whereas mutagenic effectiveness is the number of mutations induced per unit dose of a mutagen in unit time (Konzak *et al.*, 1964; Khan and Wani, 2006). These are the formulas provided by Konzak *et al.* (1965) for determining the mutagenic effectiveness and efficiency.

$$\text{Mutagenic effectiveness} = \frac{\text{Mutation frequency (MF)}}{\text{Time} \times \text{Concentration or dose}}$$

$$\text{Mutagen efficiency} = \frac{\text{Mutation frequency (MF)}}{\text{Biological damage (Lethality/Injury/Sterility)}}$$

The removal of unwanted genetic modifications to produce desired changes in the mutant is known as mutagenic efficiency. It is determined by dividing the frequency of mutations by the damages-such as mortality, injury and sterility- that result from mutagenic treatments (Konzak *et al.*, 1965; Gaul *et al.*, 1972). As a result, mutagenic efficiency provides insight into the ratio of mutation to the harmful effects of the mutagen. Therefore, when it comes to reducing a mutagen's effectiveness, mutagenic efficiency is more appropriate than mutagenic effectiveness. According to Jain and Khandelwal (2009), a mutagen with greater efficiency causes comparatively less biological harm in comparison to mutation-induced damage.

Mutation Breeding Methods

Comparing mutation breeding to traditional hybridization breeding reveals certain benefits. It skips the time-consuming processes of pollination and emasculation because it has only one parent. The source material is not required in order to enhance a

specific attribute. While hybridization works with the variance that already exists in the population, mutations produce new variants that were not previously present in the current populations. However, mutation breeding is very time-consuming and necessitates a thorough and careful screening of numerous mutant populations in order to identify acceptable mutants for subsequent selection. Finding positive mutants of interest becomes essential since mutations alter the DNA at random. Following the crossing of the two homozygous lines, the selection process begins in the third year of hybridization breeding or the F_2 generation. Dominant mutations in mutation breeding can be found in the M_1 generation, which is the first year or season. However after M_1 selfing, the heterozygous dominant will segregate in the M_2 generation. Homozygous dominant mutants will be identified by progeny testing and homozygous recessive mutants will be seen in M_2 generation.

Table 1: Differences between hybridization breeding and mutation breeding

Hybridization Breeding	Mutation Breeding
Creation of variation by crossing two genetically dissimilar parents	Creation of variation by treating with mutagens
Trait specific	Trait non-specific
Variation occurs in F_2 generation	Variation occurs in M_1 generation
Works on the variation within the limit of existing variation	New variations can occur
Specific Direction	Directionless
Less laborious	Laborious
Probability of success is more	Probability of success is less, majority are deleterious

Source: Advances in Horticultural Crop Management and Value Addition

Mutation Breeding in Seed Propagating Crops

Since chimeras are a major issue with vegetatively propagated crops, mutation breeding in seed-propagated vegetable crops that belong to the groups Solanaceae, Fabaceae, Cucurbitaceae and Malvaceae is relatively simple. Obtaining 500-1000 seeds for mutagenic treatment and transporting the seed material to the gamma chamber are simple processes. Producing both mutant and non-mutant seeds is the main obstacle in crop seed propagation. These can be fixed by using an effective screening technique and keeping a sizable population to find the desired mutations. Thus, the most often used technique in mutant breeding programs is the use of seeds for the mutagenic treatments.

Mutation Breeding in Self-Pollinated Crops: In self-fertilized crops, the mutant traits are quite simple because they occur frequently in nature. It is recommended that these materials be autogamous and undergo phenotypic screening after at least M_2 generation. The plants in this generation will undergo isolation in order to identify the recurrent mutant characteristic.

Mutation Breeding in Cross Pollinated Crops: Crops that are mostly cross-fertile are heterozygous and show a high degree of inbreeding depression, which makes the labor tiresome. It results in a significant variance in M_2 production during open pollination and selfing. There are a few major mutants of interest that can be found. The employment of mutant breeding techniques is more complicated for plant species that include self-infertility mechanisms, such as self-incompatibility.

Mutations in Vegetatively Propagated Species:

Mutation breeding in asexually propagated species like cassava, sweet potato, potato and taro differs from seed propagated crops in several ways. Mutagenic therapy in multi-cellular, actively dividing tissues such as apical or auxiliary buds, requires careful inspection for chimeric mutants.

Table 2: Differences between seed propagated and vegetatively propagated crops for mutation breeding

Seed propagated species	Vegetatively propagated species
Plant material used is seed or pollen unicellular starting material	Plant material is apical or auxiliary buds
Next generation proceeds sexually	Next generation proceeds vegetatively
Further variation occurs due to selfing	Mutation is the only source of variation
The mutagenic generations are indicated as M ₁ , M ₂ , M ₃	The mutagenic generations are indicated as M ₁ V ₁ , M ₁ V ₂ , M ₁ V ₃
No problem of Chimeras	Chimeras are the major problem
Selection starts from M ₁ or M ₂ generation	Actual selection starts from M ₁ V ₄
Comparatively consumes less time	Comparatively consumes more time

Source: Advances in Horticultural Crop Management and Value Addition

Past accomplishments: In 2009, the FAO/IAEA mutant variety database includes around 3168 mutant cultivars from over 200 plant species with a total of 3218 as of 2014.

Table 3: Significant achievements of Vegetable crops in India through Mutation Breeding

Crop	Variety	Mutant type
Tomato	S-12	X-ray mutant of Sioux
	Maruthan	Mutant of CO-1
	PKM -1	Mutant of Annagi
	Pusa Lal Meeruti	Gamma ray mutant of Meeruti
Chilli	MDU-1	Gamma Ray mutant of K-1
French Bean	Pusa Parvati	X-Ray mutant of Wax pod
Pea	L-166 (Hans)	-

Hyacinth bean	CO-10	Gamma ray mutant of CO-6
	CO-9	Spontaneous mutant
Okra	EMS-8	EMS treated mutant of Pusa Sawani
	MDU-1	Gamma ray mutant of Pusa Sawani
Bitter gourd	MDU-1	Gamma ray mutant of MC-103
Palak	Jobner Green	Spontaneous mutant from local cultivar

The list of mutant varieties released in abroad in various vegetable crops is given in Table 4 (Kalloo and Kalloo, 1988).

Table 4: Significant achievements of Vegetable crops in world through Mutation Breeding

Crop	Variety	Characteristic
Tomato	Luch 1	Early ripening mutant
	M47/13	High yield
French bean	Sanilac, Seeway, Seafarer, Gratiot, Alpha	Early maturity and disease resistance
Pea	Wasata and acasia	Leafless mutants
	Starl	Suitable for mechanical harvesting
Onion	Compass	High yield
Cassava	Ten bankye	African Cassava Mosaic Virus resistance
Pea	HUVP 1 and HUVP 2	Powdery mildew resistance 2

Conclusion

Global food demand necessitates higher crop yields, driving the need for improved varieties. Mutation breeding creates new variations for desirable traits like yield and disease resistance especially when existing variation is limited. While beneficial, it also carries risks like harmful mutations and lengthy screening processes. Modern techniques like molecular markers and TILLING enhance mutation breeding, making it a valuable tool alongside other breeding method.

References

Ashadevi, R., Koundinya, A. V. V. and Chattopadhyay, S. B. (2017). An Estimation of Effect-

- ive Mutagen Doses, Induced Genetic Variation and Characters Association in M₂ Generation of Okra. *International Journal of Current Microbiology and Applied Sciences*, 6(5): 2209-2219.
- Gupta, N. (2019). Mutation breeding in vegetable crops: A review. *International Journal of Chemical Studies*, 7(3): 3516-3519.
- Jadhav, P. A., Kalpande, H. V., Kathale, M. N. and Dahale, G. P. (2012). Effect of gamma rays and ethyl methane sulphonate on germination, pollen viability and survival of okra [*Abelmoschus esculentus* (L.) Moench]. *Journal of Crop and Weed*, 8(2): 130-131.
- Jain, S. K. and Khandelwal, V. (2009). Induced polygenic variability in black gram [*Vigna mungo* (L.) Hepper]. *The Indian Journal of Genetics and Plant Breeding*, 69(1): 72-75.
- Kaloo, D. and Kaloo, G. (1988). Vegetable Breeding. CRC Press, University of Wisconsin-Madison. Vol. 1.
- Karthika, I. R. and Subba, B. (2006). Effect of gamma rays and EMS on two varieties of soybean. *Asian Journal of Biological Sciences*, 5: 721-724.
- Konzak, C. F., Nilan, R. A., Wagner, J. and Foster, R. J. (1965). Efficient chemical mutagenesis, pp. The use of induced mutations in plant breeding. Food Agriculture Organization/International Atomic Energy Agency Technical meeting report, Pergamon Press, Oxford, UK.
- Jayakumar, S. and Selvaraj, R. (2003). Mutagenic effectiveness and efficiency of gamma rays and ethyl methane sulphonate in Sunflower (*Helianthus annus* L.). *Madras Agriculture Journal*, 90: 574-576.
- Konzak, C. F., Nilan, R. A., Wagner, J. and Foster, R. J. (1964). Efficient chemical mutagenesis. *Radiation Botany*, 5: 49-70.
- Kumar, R. and Mani, S. C. (1997). Chemical mutagenesis in manhar variety of rice (*Oryza sativa* L.). *Indian Journal of Genetics and Plant Breeding*, 57(2): 120-126.
- Lagoda, P. J. L. (2007). Effects of mutagenic agents on the DNA sequence in plants. *Plant Breeding and Genetics Newsletter*, 19: 13-14.
- Muller, H. J. (1927). Artificial transmutation of the gene. *Science*, 66: 84.
- Suprasanna, P., Jain, S. M., Ochatt, S. J., Kulkarni, V. M. and Predieri, S. (2012). Applications of in vitro techniques in mutation breeding of vegetatively propagated crops. In: Plant mutation breeding and biotechnology, (Eds: Shu, Q.Y., Forster, B.P. and Nakagawa, H), CABI International.

Clonal Selection: A Breeding Strategy for Improvement of Fruit Crops

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Abstract

A clone is a collection of plants formed from a single plant through asexual reproduction. Asexually propagated crops are sometimes referred to as clonal crops. All individuals of a clone share the same genotype. They have the same genotype as their parent plant. Asexual propagation occurs in many agricultural and horticultural crops. Asexually propagated crops differ from sexually propagated crops in that breeding materials and commercial varieties are maintained through asexual reproduction, rather than sexual reproduction in the latter. This offers unique advantages for crop breeding. Clonal selection has been used successfully in India to generate novel varieties of potato, sugarcane, banana, citrus and grapes.

Introduction

Many agricultural and horticultural crops reproduce asexually. Asexually propagated crops include sugarcane, potato, sweet potato, colocasia, ginger, turmeric, fruit trees such as mango, citrus, apple and pears, as well as ornamentals and grasses. The first person to enhance fruits by clonal cross-pollination induced genetic recombination was Thomas Andrew Knight (1759-1838). Because traditional plant breeding is evolutionary, it works well. Its foundation is the ongoing selection of better phenotypes generated by sexual recombination from genetically different populations (Janick, 2012). Large plantings and the isolation of elite selections created an environment that allowed for the spontaneous occurrence of mass and recurrent selection.

Variability must exist in the population and be heritable in order for selection to occur. They are reproduced asexually to avoid the negative effects of segregation and recombination caused by sexual reproduction. Through segregation and recombination, novel gene combinations emerge, resulting in unique genotypes and phenotypes for offspring. In contrast, asexual reproduction creates identical progeny. Progeny are formed from vegetative cells by mitosis and inherit their parents' genotypes. Asexual reproduction has the advantage of preserving an individual's genotype indefinitely. It must be noted that asexual reproduction allows for the preservation and maintenance of any genotype, regardless of homozygosity. Self-pollination preserves homozygous traits. Pure-lines are formed from

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genotypes.

Clone: A clone is a collection of plants formed from a single plant through asexual reproduction. Asexually propagated crops are sometimes referred to as clonal crops. All individuals of a clone share the same genotype. In terms of genotype, they are identical to the parent plant. Therefore, phenotypic changes inside a clone are solely due to environmental factors and selection within a clone is ineffective.

Characteristics of Clones

Identical genotype: All individuals in a clone share the same genotype. Clones are obtained and maintained through asexual reproduction, including mitosis. Only cell division. Genetic diversity in progeny is mostly caused by segregation and recombination during meiosis alone. A clone's genotype remains unchanged for an indefinite period.

Lack of genetic variation: A clone's phenotypic variation is solely due to environmental factors, as all individuals have the same genotype.

A clone's phenotype is influenced by its genotype (G), environment (E) and genotype-environment interaction (GE) compared to the population mean. The phenotype (P) of a clone can be expressed as follows.

$$P = Q + G + E + GE$$

Clone phenotypic differences can be attributed to both genotype and E/GE components. Thus, the efficiency of selection among clones like pure-lines would depend. The accuracy with which

E and GE components of phenotypic are estimated.

Immortality: Clones can be maintained indefinitely through asexual reproduction which making them theoretically immortal. Clones can deteriorate due to viral or bacterial infections and some may become extinct due to disease or pest vulnerability. Furthermore, genetic heterogeneity within a clone can alter its properties.

Inbreeding depression: Clones are typically heterozygous and exhibit significant vigor loss due to inbreeding.

Origin of Genetic Variation within Clones

Genetic variation within clones may arise due to

- ✓ Somatic mutation
- ✓ Mechanical mixture
- ✓ Occasional sexual reproduction

Mutation: Somatic mutations are sometimes called bud mutations. The frequency of mutations is normally relatively modest (10^5 - 10^7). Ordinarily, dominating mutations would be expressed in somatic tissues since recessive mutations can be expressed only in homozygous situation. A mutant allele is considered homozygous if both copies of a gene in a cell mutate simultaneously, resulting in the identical mutant allele. The mutant allele is already heterozygous in the original clone. Both of these instances are plausible, but they are likely to be unusual. Therefore, we can assume that dominant bud mutations occur more frequently than recessive ones. Bud mutations can result in chimeras, which are persons with cells from many genotypes. Non-chimera plants can be generated from chimeras using

various approaches making it a minor issue. Bud selection involves selecting mutant buds or branches to create desirable clones. Bud selection has some significance in the improvement of perennial crops. Like fruit trees or crops that do not blossom. Detecting mutant buds/branches would necessitate extensive plant observation and multiple trained individuals. Bud selection is typically done at commercial plantations rather than breeders' nurseries. Desirable bud mutations were discovered by chance rather than through a targeted search.

Mechanical Mixture: Mechanical blending leads to genetic variance within clones similar to pure-lines.

Sexual reproduction: Sexual reproduction can lead to segregation and recombination. Thus, the seedlings obtained through sexual reproduction in a clone the asexual progeny diverge from the genotype. Old clones of annual and biennial crops such as potatoes are known to become varied. Selecting from an older clone can lead to a better clone. Kufri red potato is a selection of Darjeeling Red Round, derived from a disease-free plant. Similarly, Kufri safed potato comes from Phulwa.

Clonal Degeneration

Clones can be kept indefinitely, making them theoretically immortal. However, clones have a limited life and older clones lose vigor and production. Clonal degeneration occurs when clones lose their vitality and productivity over time. The term clonal degeneration implies that the degeneration is inherent in the clone, *i.e.* it is due to the vegetative reproduction itself. However, there is

little evidence that vegetative reproduction impacts the vigour or yield of clones. In contrast, asexual reproduction preserves the unique gene combination. This distinguishes one clone from others and makes it more valuable. Detailed studies show that clonal degeneration may result from

- ✓ Mutation
- ✓ Viral
- ✓ Bacterial diseases

Mutation: Mutation is a recurring process that might cause problems over time. Furthermore, certain mutations occur often. For example, 'bolter' mutations in potatoes occur at a frequency 10 in some clones and pose a major maintenance issue.

Viral diseases: Viral infections are easily spread by vegetative propagules. As a result, in clonal crops they spread rapidly over time. Viruses are likely the leading cause of clonal degeneration. A solitary cause. A virus causes ratoon stunting disease in sugarcane (*S. officinarum*). Viral infections have caused significant loss of potato clones.

Bacterial diseases: Some cases of clonal degeneration may be caused by bacterial infections. Further investigation is anticipated to reveal that most cases of clonal degeneration are caused by bacterial or viral infections.

Methods of Improvement of Clonal Crops

Asexually propagated crops differ from sexually propagated crops in that they retain breeding materials and commercial variations by asexual reproduction rather than sexual reproduction. The case of the latter. This offers unique advantages

for crop breeding. A single excellent plant from a population can lead to the creation of a new variety. Furthermore, the genotype of this plant is irrelevant as there will be no sexual reproduction. This remarkable plant could be picked from an old unimproved variety, an improved variety that has become variable or a population created by crossing multiple clones. As in the case of sexually reproducing crops, breeding of clonal crops has the following two well defined phases:

- ✓ Genetic variety can occur naturally or by human effort such as hybridization.
- ✓ Choose the optimal genotype from the variable population to create a superior clone or variation. Clonal selection refers to the process of using selected plants to create new clones for crops. This article will cover the fundamentals of clonal selection and how to create genetic variety through hybridization.

Clonal Selection: The phenotypic value of a plant or clone is due to the effects of its genotype (G), the environment (E) and genotype environment (GE) interaction. Only the G effects are heritable. Using single plant observations to select for quantitative traits is unreliable and the results may be no better than a random selection. Character selection based on unreplicated clonal plots can be misleading and unreliable, including yielding abilities. Replicated yield experiments are necessary to determine the value of a clone with accuracy. Selection for heritable traits like plant height, flowering time, color and disease resistance can be done on individ-

ual plants or plots making it simple and effective. These circumstances are analogous to sexual reproduction in crops.

Selection procedure

First year: Select a few hundred to thousand attractive plants from a mixed population and collect their propagules individually. A rigorous selection can be made for simple. Characters that were inherited have a high heritability. Plants with obvious flaws are rejected.

Second year: Clones from selected plants are typically developed without duplication due to limited propagation material and a high number of plants. Clones were involved. Clones traits will become clearer compared to prior generations, which relied on individual plants for observations. Eliminating poor clones reduces the number of clones significantly. The selection is based on visual observations and on the breeder's judgment of the value of clones. Fifty to one hundred clones may be selected on the basis of clonal characteristics.

Third year: A preliminary yield trial is replicated and compared with appropriate inspections. A few high-performing clones with desirable traits are chosen. Multiple-location trials. Quality selection occurs at this stage as well. Separate disease nurseries can be established to assess the disease resistance of specific clones.

Fourth to sixth years: Replicated yield studies are undertaken at multiple locations with appropriate checks. The yielding ability, quality, and disease resistance of clones are strictly controlled and evalu-

ated. The best clone that outperforms the checks in one or more criteria is released as a new variety.

Seventh year: The superior clone is multiplied and released as a new variety.

Merits of clonal selection

- ✓ It is the only method of selection that applies to clonal crops. It prevents inbreeding depression and protects the gene combinations found in clones.
- ✓ Combining clonal selection with hybridization can create the necessary variability for selection without significant alteration.
- ✓ The selection technique helps to retain the purity of clones.

Demerits of clonal selection

- ✓ This selection strategy uses the population's existing variability rather than creating it.
- ✓ Sexual reproduction is necessary for the development of variety. Through hybridization.

Achievements of clonal selection

In India, clonal selection has been successfully utilized to develop improved varieties in fruit crops such as banana, citrus, grapes and mango. Notable examples include Ko 11, Ko 22 and Neelam in mango; Bombay Green, Pride Monthan and High Gate in banana. These were developed through interspecific hybridization followed by clonal selection. A clonal selection of seedling progenies of the Kadayam variety from the Tirunelveli district of Tamil Nadu led to the release of PKM 1 lime. Additionally, many commercially important mango varieties worldwide, such as Dashehari, Langra, S.B.

Chausa, Rataul and Swarnarekha, originated through open pollinated selection. Prominent seedling selections promoted globally include Tommy Atkins from Haden, Keitt from Mulgoa, Dyke and Palmer of unknown origin, Irwin from Lippins, Golden Nuggets and Brooks from Sandersha and Sensation from unknown origin

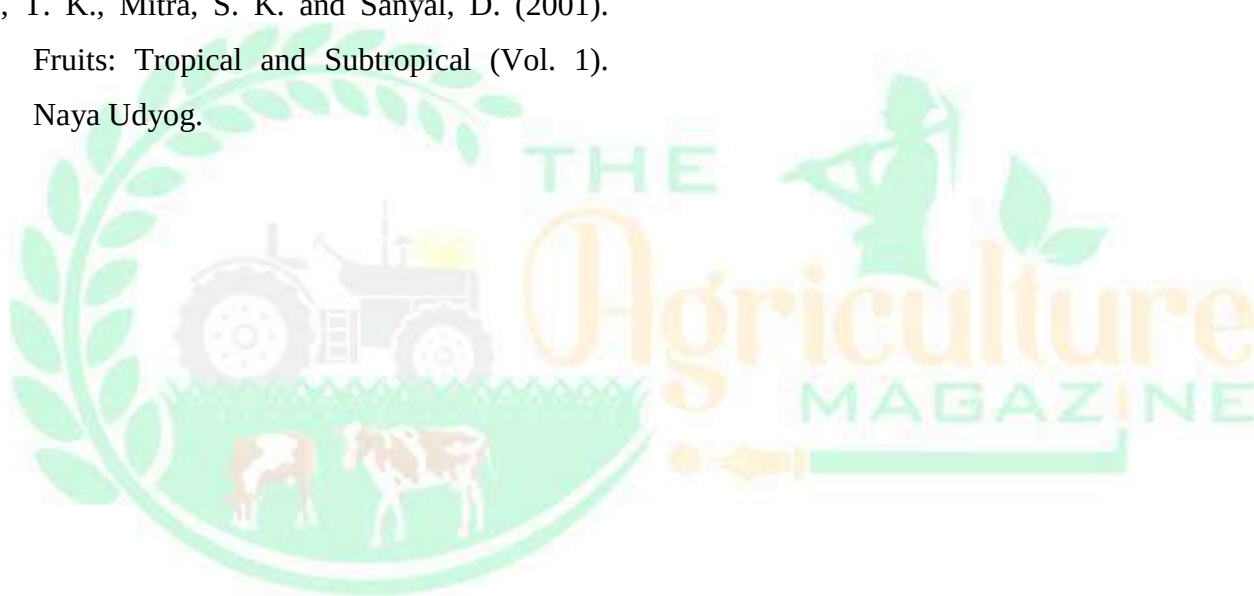
Conclusion

Clonal selection is a vital breeding strategy for the improvement of asexually propagated crops allowing the preservation and multiplication of superior genotypes without the risks of genetic segregation. It offers a reliable approach to enhance desirable traits such as yield, quality and disease resistance. While, it does not generate new variability, combining it with hybridization can effectively address this limitation. Successful applications in crops like banana, mango, citrus and grapes highlight its practical value in crop improvement programs.

References

- Ferwerda, F. P. and Wit, F. (1969). Outlines of Perennial Crop Breeding in the Tropics. Veeran and Zonen, (Eds.), Wageningen, The Netherlands.
- Janick, J. (2012). Fruit breeding: past, present and future. In XXII Congresso Brasileiro de Fruticultura, Bento Goncalves-RS. 22 (26): 1-22.
- Poelhman, J. M. and Borthakur, D. N. (1969). Breeding Asian Field Crops with Special Reference to Crops of India. Oxford and IBH Publishing Co., New Delhi.

- Poehlman, J. M. and Sleper, D. A. (1961-1995).
Breeding Field Crops. Panima Publ. Crop.,
New Delhi. Simmonds NW. Mating systems
and breeding of perennial crops. Advance-
ment Sci., London, 18: 183-186.
- Sengar, J., Yadav, G. and Soni, A. Genetic diversity
and breeding in fruit science. *Diverse
Insights of Fruit Science*, 134.
- Simmonds, N. W. (1979) Principles of Crop Impro-
vement. Longman, London and New York.
- Bose, T. K., Mitra, S. K. and Sanyal, D. (2001).
Fruits: Tropical and Subtropical (Vol. 1).
Naya Udyog.



Integrating Natural Predators for Sustainable Pest Management in Agriculture

Subham Kandwal, Garima Khakriyal and Dipti Joshi

Abstract

In agriculture, the balance between cultivation and nature has always been delicate. Farmers and agriculturalists strive to maximise yield and ensure the health of their crops and livestock. Among these natural elements, predators play a crucial role in maintaining ecological balance. Predators, including coccinellids (ladybird beetles), chrysopids (green lacewings), syrphid flies, predatory mites, anthocorid bugs and spiders are vital in controlling populations of aphids, whiteflies, thrips, mites, mealybugs and other economically significant pests. By feeding directly on these pests at various developmental stages, they help prevent population buildup and maintain ecological stability within agricultural ecosystems. This article examines the importance of education and awareness in fostering a harmonious relationship between agricultural practices and natural predators, highlighting the benefits of this alliance for sustainable farming.

Introduction

Globally, agriculture and forest ecosystems thrive thanks to the remarkable balance between crops, beneficial insects and natural processes. Farmers and scientists have long worked together to harness this balance, developing innovative strategies to protect yields and ensure food security. With advances in sustainable practices and integrated pest management, we now have powerful tools to safeguard crops while preserving ecological health. Despite these efforts, crop destruction from pest infestations remains a serious global concern, affecting not only agricultural production but also

forest ecosystems. This challenge has been recognized since the earliest days of crop cultivation. In earlier times, chemical pesticides were the primary tool for pest control; however, their overuse in farming has resulted in numerous adverse effects. Pesticides often disrupt the natural balance of ecosystems by killing not only harmful pests but also beneficial insects such as predators and parasitoids. When these natural enemies are eliminated, pest populations can increase rapidly, leading to pest resurgence and secondary outbreaks. In addition, greater exposure to pesticide residues has become a serious concern for human health.

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Against this backdrop, natural predators emerge as vital allies in sustainable pest management. Generally, crop protection occurs naturally through the interaction among the host plant, pest and their natural enemies without affecting the environment, causing no harm to humans and no extra cost of cultivation. Predators are species that feed upon other animals (i.e., prey) for their development, survival and reproduction. They are usually larger and more active than their prey and often depend on multiple prey species to complete their life cycle. Equipped with specialised adaptations for locating, capturing and consuming prey, predators play a crucial role in maintaining ecological balance and stability.

The idea that insects can be intentionally used to reduce the populations of other insects is not new. It appears that this practice was first observed by the Chinese, where predatory ants were used naturally to manage specific citrus bug problems. In fact, citrus growers in the Orient maintain and sometimes buy colonies of the predatory ant *Oecophylla maragdina* and place them on orange trees to reduce the number of leaf-feeding insects. In Europe, Réaumur was the first to propose biological control in 1734. He suggested releasing lacewings in greenhouses to control aphids. The first successful classical biological control of a weed was achieved in India when the cochineal insect *Dactylopius ceylonicus* was unintentionally introduced from Brazil in place of *Dactylopius cacti* to produce dye from *Opuntia vulgaris*. Between 1863 and 1868, this led to the first

intentional use of an insect to control a weed. In 1898, lady bird beetle, *Cryptolaemus montrouzieri*, was introduced into India from Australia for the control of citrus mealybug.

This agricultural practice has continued over time and represents the first known example of humans moving natural enemies for biological control. Using predatory or insect-eating arthropods as biological control agents is very useful in managing insect pests. More than 30 families of insects are predaceous in nature, and among them, Coccinellidae, Chrysopidae, Syrphidae, Anthocoridae, Staphylinidae, Cecidomyiidae, Reduviidae, Carabidae and Formicidae are important in perspective. Arthropod predators can be classified into two groups according to their food habits:

- ✓ Generalist predators that depend on prey of different insect families and feed on different stages of prey (egg, larva, pupa and adult). These generalist predators can be increased by conservation of biocontrol techniques or augmentative releases.
- ✓ Specialised predators can be introduced to a new site as part of classical biological control programs.

Limitations of Natural Predators in Pest Management

Natural predators play an important role in maintaining ecological balance and reducing the use of chemical pesticides. They help regulate pest populations in a sustainable and environmentally friendly manner. However, their effectiveness is

Table 1: List of Arthropod predators effective against major insect pests of various crops

Natural Enemy	Pest	Crop
The ladybird beetles <i>Menochilus sexmaculatus</i> <i>Coccinella septempunctata</i>	Aphids; <i>Aphis craccivora</i> , <i>Myzus persicae</i> , <i>Lipaphis erysimi</i> (Hemiptera: Aphididae) and Leafhoppers; <i>Empoasca kerri</i> , <i>E. facialis</i> , <i>E. fabae</i> (Hemiptera: Cicadellidae) etc.	Vegetables, Fruits, Pulses, Oilseeds
Lacewings <i>Chrysoperla zastrowi sillemi</i>		
Predatory mites such as <i>Phytoseilus persimilis</i> and several species of <i>Amblyseius</i> spp.	Spider mite; <i>Tetranychus</i> spp. (Acari: Tetranychidae)	Tomato, Cucumber, Brinjal, Sweet Peppers,
<i>Cryptolaemus montrouzieri</i> , <i>Scymnus</i> spp.	Mealybugs, <i>Paracoccus marginatus</i> and <i>Phenacoccus solenopsis</i> , green shield scale: <i>Pulvinaria psidii</i> (Hemiptera: Pseudococcidae), etc.	Brinjal, Okra, Tomato, Papaya, Guava, Sapota, Lemon
Coccinellids, <i>Chilocorus nigrita</i> and <i>C. circumdatus</i>	Green scale, <i>Coccus viridis</i> (Hemiptera: Coccidae) on acid lime and white scale <i>Aulacaspis tubercularis</i> on mango (Hemiptera: Diaspididae)	Acid lime, Mango
Predatory mirid bugs, <i>Nesidiocoris tenuis</i>	Tomato pinworm, <i>Tuta absoluta</i> (Lepidoptera: Gelechiidae), etc.	Tomato, Potato, Pepper

influenced by several limitations. Factors such as climate variability and availability of food resources can reduce predator-prey interactions and delay pest suppression. Non-target effects of pesticides may also decrease predator populations and disrupt biological control programs, making chemical use a continuing challenge. Another important limitation is the time required for predator establishment. Natural enemies need time to multiply and build up sufficient numbers in the field. During sudden pest outbreaks, they may not provide immediate control, leading farmers to depend on chemical treatments for quick results. The introduction of non-native predators in classical biological control programs may also create ecological risks, including competition with native species and disturbance of local ecosystems. Economic constraints are also significant, as farmers may incur initial costs for training, conservation practices, or predator introduction, while benefits may appear only gradually. Therefore, integrated strategies that combine conservation of natural enemies, farmer education

and regular monitoring are essential to maximize benefits and minimize risks.



Predators Recorded from Different Study Sites

Education and Awareness: The Key to Accepting Natural Predators

While the benefits of accepting and supporting natural predators in agriculture are clear, several challenges limit their acceptance. Farmer resistance, lack of awareness and economic concerns remain major constraints. Despite their benefits, the presence of predators on farms is often viewed negatively. This misperception stems largely from limited knowledge of insect taxonomy and ecological roles. Educating farmers and the public about the ecological role of predators and their long-term benefits can help change negative perceptions. When people understand natural cycles and how predators help to maintain the health of the ecosystem, including agricultural lands, they can make informed decisions that protect both their livelihoods and the environment

Conclusion

Education and awareness are key to changing perceptions and practices regarding natural predators in agriculture. By understanding the ecological benefits of predators and implementing strategies that support their presence, farmers can contribute to a balanced ecosystem that supports both agricultural productivity and biodiversity. The path forward requires collaboration, innovation and a commitment to sustainable practices that honour the intricate connections between agriculture and the natural world.

Sea Weed Extract: An Organic Substitute for Sustainable Agriculture

Karri Sarika and G. Janakiram

Seaweeds have been widely used in agriculture since ancient times, notably in regions such as the Roman Empire, Japan, China, France, Spain, and Britain. Coastal communities around the world have traditionally utilized seaweeds as natural fertilizers to boost crop production. Today, seaweed extracts are applied in various ways such as seed treatments, foliar sprays and soil applications to promote plant growth and protect crops. Unlike chemical fertilizers, seaweed extracts are biodegradable, non-toxic, and environmentally friendly, making them especially valuable in modern sustainable agriculture, including organic and integrated organic farming.



Sea Weed Extract *Ascophyllum nodosum* sea weed

These extracts enhance overall plant health by stimulating growth, improving seedling development, encouraging root hair and secondary root formation, and increasing nutrient uptake. They also support better fruit setting, improve resistance to pests and diseases, and help plants manage environmental stresses like drought, salinity, and extreme temperatures. Nowadays, seaweed extracts are sold commercially under names like Goemar

GA14, Seaspray, Seasol, SM3, Cytex, Seacrop 16, Maxicrop (Sea Born), Algifert (marinure), and Kelpak 66.

Application Methods

There are several ways to apply seaweed extract, including foliar spraying, soil drenching, and root application. The best approach is determined by the particular needs of your plants and the directions that come with the product that contains seaweed extract.

Foliar spray: Pour the diluted seaweed extract solution into a sprayer and uniformly mist the plant leaves. Ensure adequate coverage by covering the leaves on both sides. This process enables rapid nutrient absorption through the leaves.

Soil drench: Pour the diluted seaweed extract solution slowly around the base of the plants, aiming it at the root zone. This technique improves soil health and helps get nutrients straight to the roots.

Root application: The diluted seaweed extract solution can be applied directly to the base of the plants or used when watering. By ensuring that the roots come into contact with the extract, this technique facilitates the absorption of nutrients. This usually entails combining a specific quantity of seaweed extract with water. Although dilution ratios might differ, it is generally advised to dilute one part seaweed extract with twenty parts water.

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Benefits in Agriculture

- ✓ The substantial amount of organic matter in seaweed fertiliser helps to keep moisture and minerals at the higher soil level that are accessible to the roots, making it superior to chemical fertilisers.
- ✓ Seaweed fertilisers are more cost-effective and superior to conventional fertilisers, according to recent research.
- ✓ Seaweed extract's biodegradable, non-toxic, and environmentally friendly qualities make it more beneficial than chemical fertiliser.
- ✓ One of the most significant marine resources in the world, seaweeds are utilised as raw materials for several industries, animal feed, and human consumption and are also utilised as crop manure in horticulture and agriculture.

Conclusion

Around the world, using seaweeds and their extracts in agriculture is growing in popularity. The only way to properly utilise them for agricultural production is through additional investigation of their biochemical makeup and mode of operation. Additionally, seaweed extracts have the potential to be used in fields and are known to shield plants from a variety of biotic and abiotic challenges. Therefore, it should be a top priority to conduct research into creating sustainable ways to reduce these strains. Extracts from seaweed are used in agriculture to help protect the environment and lessen the use of dangerous agrochemicals. Their incorporation into widely used farming techniques around the world

can increase crop yields in a sustainable way.

Carbon Credits Farming

Seema Hodkashia and Sarvendra Kumar

Introduction

Increasing awareness of climate change and global warming identifies the emissions of CO₂ and other greenhouse gases (GHGs) as possible causes of climate change, causing harmful impacts on humans, economies and livelihoods. The agricultural sector plays a dual role in climate change as a significant emitter of greenhouse gases (GHGs) and a potential sink for atmospheric carbon dioxide through various practices that enhance carbon sequestration. With increasing global emphasis on achieving net-zero emissions and sustainable development goals, carbon credits in agriculture have emerged as a promising mechanism to incentivize practices that reduce emissions and sequester carbon in soils and biomass. The transition from the Kyoto Protocol to the Paris Agreement has brought significant changes to the landscape of carbon markets, with an emphasis on shared responsibility and the need for all countries to set emission reduction targets through nationally determined contributions (NDCs) (The Intergovernmental Panel on Climate, 2022). The “4 per mille” initiative launched at COP21 aspires to increase global soil organic matter stocks by 0.4% annually, potentially offsetting 20-35% of anthropogenic GHGs emissions with improved soil carbon management, especially in managed agricultural lands (Field *et al.*, 2017). Such ambitious targets

highlight the large potential of soil carbon sequestration for climate mitigation. India's agriculture sector can transition from a net GHGs emitter to an absorber by adopting sustainable practices, reducing emissions by 84% by 2070, through a voluntary carbon credit trading system supported by a measurement and verification platform. This article explores the concept of carbon credit farming, its operational framework, key management practices, and benefits related to sustainable agriculture and climate change mitigation.

What is Carbon Credits farming?

The term “Carbon credits farming” can be defined in various ways. The European Union favours a broad definition that involves all field-level management of carbon pools, flows, and greenhouse gas fluxes to mitigate climate change. On the other hand, some researchers use a narrow definition that concentrates on carbon sinks in soils and vegetation as well as methods to preserve or enhance them, like reforestation or afforestation to boost above-ground biomass and changing cropping or grazing schedules to increase soil organic carbon. Carbon credits represent tradable certificates or permits that quantify the reduction of one metric ton of carbon dioxide equivalent (CO₂e) emissions. In agriculture, these credits are generated by adopting practices that either reduce emissions or increase the sequestration

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of carbon in plants and soils. Farmers and agricultural producers earn carbon credits by implementing sustainable agricultural techniques and can sell these credits to industries or entities that need to offset their emissions.

How does the System Work?

From the initial implementation of sustainable practices to farmers receiving payment for carbon credits, several key stages must be completed (Fig. 1). These include assessing the current level of carbon sequestration in the soil and verifying the results of the practices implemented. A simplified step-by-step process about carbon credits for farmers focused on entering the specialized market and obtaining credits with the help of a project developer.

Find a Carbon Project Developer: Farmers usually start by locating a project developer who can guide them through the buy and sell process.

Provide Farm Information: Farmers share basic details about the farm, including current practices, future plans, and the location of fields.

Initial Estimation: The project developer uses farmer's data to estimate how many CO₂ offsets a farm could potentially generate.

Implement Regenerative Practices: Farmers adopt additional regenerative farming practices, such as cover cropping or reduced tillage, that enhance SOC sequestration.

Data Collection and Monitoring: After a year or so, data on the effects of practices on the farm can be gathered and analyzed to assess the amount of SOC

sequestered.

Verification: An expert collects, analyzes, and verifies the farm's data. To ensure accuracy, they might conduct a site visit or use remote sensing technology. The verifier calculates the number of CO₂ offsets earned.

Sell Carbon Credits: Once verified, carbon offsets can be sold on the voluntary market, providing farmers with a new revenue stream.

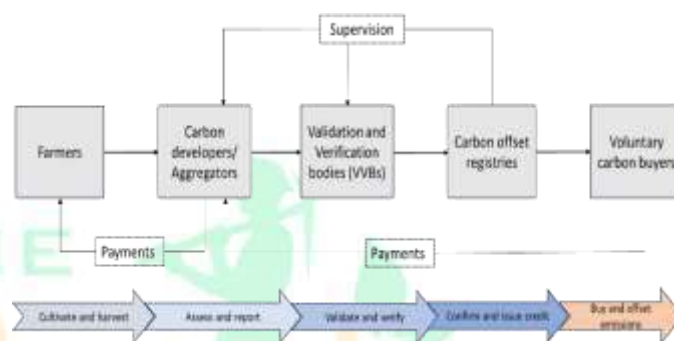


Fig. 1: Carbon credit management chain for farmers

How do farmers get carbon credits?

Farmers can get carbon credits from soil restoration and management, agroforestry, enhancement of soil organic carbon (SOC), nutrient management, and livestock management practices. The equilibrium between carbon inputs to the soil, such as biomass, and carbon loss pathways, such as respiration, decomposition, and erosion, causes soil organic carbon to build up. Soils become a net carbon sink when carbon inputs exceed carbon losses from erosion and decomposition. Increasing carbon inputs and/or reducing carbon losses are necessary for soil carbon management in agricultural lands. This can be achieved through a number of techniques (Table 1). Both the public and private sectors are paying more attention to encouraging farmers to use beneficial

cultivation practices to increase carbon sequestration as part of climate change mitigation strategies because of the significant SOC storage potential of agricultural soils as a crucial part of negative emissions strategies based on natural and working lands. These sustainable approaches help transform agricultural landscapes from net emitters to net absorbers of GHGs, contributing both to food security and climate change mitigation.

Table 1: Key management options for SOC enhancement

Carbon farming practices	Role
No-till or reduced tillage	Minimize soil disturbance and carbon loss
Cover cropping	Keep soil covered and enhance organic matter
Agroforestry	Offers multiple benefits, including carbon storage in woody biomass and soil, biodiversity conservation, and climate resilience
Crop rotation	Diversify plantings and improve soil health and reduce GHGs emission
Improved nutrient and manure management	Improve soil carbon content and reduce nitrous oxide emissions
Irrigation and water management	Lower methane emissions, especially in rice cultivation
Biochar Application	Improve soil properties and acts as a stable form of carbon sequestration
Land levelling	Lower GHGs emissions from improved water use efficiency

Economic and environmental benefits

The adoption of carbon credit farming in agriculture plays an important role.

Economic Incentives for Farmers: Carbon credits offer additional income streams to farmers by providing environmental protection. This economic benefit enhances farm viability and motivates the adoption of sustainable practices. The carbon credit system offers financial incentives to farmers adopting practices that improve soil carbon stocks.

These incentives help overcome initial adoption barriers such as financial constraints and access to credit, enabling investments in organic amendments and improved land management (Kayusi *et al.*, 2025).

Reduction in Greenhouse Gas Emissions:

Agricultural sectors implementing carbon-friendly practices significantly reduce emissions of methane, nitrous oxide, and carbon dioxide, contributing to national and international climate commitments.

Improvement of Soil Health and Productivity:

Carbon credit farming practices increase soil organic matter, enhance nutrient cycling, and improve water retention and leads to a more productive soil and increased crop yield. Pastures and legumes rotated in a ley farming system increased the carbon sequestration rate of $0.26 \text{ t C ha}^{-1} \text{ year}^{-1}$ when no till and stubble retention were practiced (Dalal *et al.*, 2011).

Biodiversity Conservation: Carbon credit farming has the potential to advance biodiversity conservation by affecting the restoration of native species and ecosystems, encourage diverse species plantings rather than monocultures (Standish *et al.*, 2014). Agroforestry systems enhance species richness, stabilize soil, and provide habitat for wildlife.

Conclusion

The integration of carbon credit systems into agriculture presents a transformative opportunity for climate change mitigation, sustainable farming, and economic development. These credits encourage the

adoption of regenerative practices that restore soil health, increase biodiversity, and raise farmer incomes by encouraging carbon sequestration and lowering greenhouse gas emissions. As global efforts toward net-zero emissions and sustainable food systems, agricultural carbon credit mechanisms offer a scalable and equitable solution to support environmental and socio-economic goals.

References

- Bashmakov, I. A., Nilsson, L. J., Acquaye, A., Bataille, C., Cullen, J. M., Fishedick, M., ... and Tanaka, K. (2022). Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change, Ch. 11.
- Standish, R. J. and Hulvey, K. B. (2014). Co-benefits of planting species mixes in carbon projects. *Ecological Management & Restoration*, 15(1): 26-29.
- Kayusi, F., Ngala, D. K. and Chavula, P. (2025). Assessing the Unfulfilled Promises of Agroforestry and Conservation Agriculture as Climate-Smart Solutions for Food Security in Kenya, Tanzania, Uganda, and Zimbabwe. *East African Journal of Agriculture and Biotechnology*. <https://doi.org/10.37284/eajab.8.1.2975>
- Field, D., Malone, B., McBratney, A., Minasny, B., Odeh, I., Padarian Campusano, J., ... and Winowiecki, L. (2017). Soil carbon 4 per mille.
- Dalal, R. C., Allen, D. E., Wang, W. J., Reeves, S. and Gibson, I. (2011). Organic carbon and total nitrogen stocks in a Vertisol following 40 years of no-tillage, crop residue retention and nitrogen fertilisation. *Soil and Tillage Research*, 112(2): 133-139.

Influence of Pre-Harvest Soil and Nutrient Factors on Postharvest Quality of Fruits and Vegetables

Renu Kapoor, Vipin Guleria, Rajesh Klare, Dharminder Kumar, Sushil Dhiman, Jaya Chaudhary, Anurag Shama and Meera Devi

Abstract

Fruits and vegetables are vital components of human nutrition and serve as an important source of income for farmers. However, their highly perishable nature leads to considerable postharvest losses, particularly in developing countries. In India, postharvest losses of fruits and vegetables are estimated to range between 25-40%, largely due to inadequate pre-harvest and postharvest management practices. Although postharvest technologies help in maintaining quality, the foundation for superior produce quality is established during the pre-harvest stage. Pre-harvest factors such as soil fertility, nutrient management, soil texture, irrigation practices, and climatic conditions significantly influence the physiological, biochemical, and structural characteristics of horticultural crops. Balanced nutrient management improves fruit firmness, sugar-acid balance, and vitamin content, while reducing physiological disorders and enhancing storage life. This chapter discusses the influence of soil properties, macronutrients, micronutrients, and irrigation practices on postharvest quality. Understanding the relationship between pre-harvest factors and postharvest behavior of horticultural produce is essential for improving quality, reducing losses, and enhancing the efficiency of the horticultural supply chain.

Introduction

Fruits and vegetables play a vital role in ensuring nutritional security and generating high income for growers. The quality of horticultural produce depends not only on production but also on proper harvesting, packaging, storage, and transportation practices. However, once a crop is harvested, its quality cannot be improved; it can only be maintained through proper postharvest management.

Due to their high moisture content, fruits and vegetables are highly perishable and prone to rapid deterioration. Even after harvest, they remain biologically active and continue physiological processes such as respiration, transpiration, ripening, and various biochemical reactions, which lead to quality deterioration over time (Kader, 2002). In India, postharvest losses of fruits and vegetables are estimated to range between 25-40%, depending on

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the commodity and the pre- and postharvest handling practices (Nanda *et al.*, 2012). These losses may occur at different stages, including harvesting, handling in the field, packing houses, storage facilities, transportation, and marketing channels. The quality of fresh produce is governed by several factors such as infrastructure, production practices, postharvest handling, and marketing systems. Post-harvest management actually begins with proper pre-harvest management practices. The attainment of optimum postharvest quality of fruits and vegetables starts early during farm planning and crop production. The effects of pre-harvest factors on postharvest quality are often overlooked or underestimated. However, many decisions made during crop production significantly influence the postharvest quality of horticultural crops. Once harvested, the overall quality of fresh produce can hardly be improved but can only be preserved through proper handling (Wills *et al.*, 2016). Therefore, it is essential to consider pre-harvest factors that help maximize the quality of fruits and vegetables entering the storage and marketing chain. Important pre-harvest factors include soil quality, nutrient management, irrigation practices, pest and disease management, and prevailing climatic conditions. These factors influence fruit quality and storage potential by modifying the physiology, chemical composition, and morphology of the produce (Saltveit, 2005). Among these factors, soil fertility and nutrient management play a crucial role in determining crop quality at harvest.

Nutrient deficiencies or imbalances in soil can significantly affect the appearance, composition, and shelf life of fruits and vegetables. The relationship between soil fertility and crop quality is complex and depends on environmental conditions such as temperature, soil moisture, soil pH, and interactions among nutrients. Fertilizer imbalance may lead to physiological disorders that ultimately reduce consumer acceptance during the postharvest period.

Soil Factors Affecting Postharvest Quality

Soil plays a critical role in determining crop growth, yield, and quality. Soil properties such as texture, structure, drainage, organic matter content, pH, and nutrient availability directly influence plant growth and fruit development. Maintaining long-term soil health and fertility is a fundamental objective of sustainable crop production systems. Healthy soils provide essential nutrients throughout the growing season, ensuring proper plant physiological functions. Soil reaction (pH) and organic matter content are important because it affects nutrient availability and microbial activity in soil. Extreme soil pH may cause nutrient deficiencies or toxicities, which ultimately affect the quality, shelf life, and storage behavior of fruits and vegetables (Brady and Weil, 2017).

Role of Macronutrients in Postharvest Quality

Nitrogen is an essential component of amino acids, proteins, nucleic acids, and chlorophyll, making it vital for plant growth and development. Because of nitrogen's involvement in protein synthesis, soil nitrogen deficiencies may lead to

lower protein concentrations in vegetables, thereby affecting the nutritional composition of the crop. Adequate nitrogen supply improves vegetative growth and enhances quality attributes such as color, flavor, and nutritional composition. On the other hand, excessive nitrogen fertilization can negatively affect quality attributes. High nitrogen levels have been reported to reduce vitamin C content in leafy vegetables such as Swiss chard, alter celery flavor, induce hollow stem in broccoli, increase susceptibility to soft rot in stored tomatoes, and increase weight loss in sweet potato during storage (Kader, 2002). Excess nitrogen may also lower sugar content and acidity in fruits. Leafy vegetables grown under high nitrogen fertilization may accumulate excessive nitrates, posing potential health concerns. Moreover, crops with high nitrogen levels often exhibit reduced storage life and increased susceptibility to mechanical injury, physiological disorders, and microbial decay (Wills *et al.*, 2016). Balanced nitrogen fertilization improves fruit firmness, color, and shelf life (Dorais *et al.*, 2001).

Phosphorus is another essential macro-nutrient involved in energy transfer, nucleic acid synthesis, and membrane structure in plants. It also plays a significant role in regulating metabolic processes, root development, cell division and balancing nitrogen utilization. Adequate phosphorus nutrition enhances fruit development and improves the sugar-acid balance in fruits. For instance, increased phosphorus supply in citrus has been reported to decrease fruit acidity and ascorbic acid

content to some extent. However, excessive phosphorus may affect the availability of micronutrients such as zinc and iron, which can indirectly influence crop quality (Marschner, 2012).

Potassium plays a crucial role in enzyme activation, carbohydrate metabolism, and regulation of plant water balance. Potassium is often referred to as the “quality element” in horticultural crops due to its significant influence on fruit development and quality. Higher potassium availability has been associated with improved fruit color, increased vitamin C content, enhanced titratable acidity, and better flavor. In crops such as tomato, potassium application helps reduce physiological disorders like blotchy ripening. In citrus fruits, potassium fertilization has been shown to increase juice content, acidity and ascorbic acid content (Marschner, 2012; Lester *et al.*, 2010).

Micronutrients and Physiological Disorders

Micronutrients play a vital role in plant metabolic processes, and their deficiency can lead to several physiological disorders that reduce both yield and quality.

- ✓ Calcium deficiency causes blossom end rot in tomato, capsicum, and watermelon; tip burn in lettuce, cabbage, and cauliflower; blackheart in celery; bitter pit in apple and pear and red blotch of lemons. Adequate calcium levels improve fruit firmness, storage life, vitamin C content, and resistance to physiological disorders by reducing respiration and ethylene production (White and Broadley, 2003).

- ✓ Boron deficiency leads to browning of cauliflower curds, internal necrosis in mango, lumpiness in papaya, fruit cracking in pomegranate, russetting and internal cork in apple croking of apples, apricot: and lumpy rind of citrus fruit. Foliar spraying of 0.1-0.2% boric acid or borax during flowering and fruit development stages is also effective in preventing disorders such as fruit cracking, internal necrosis, and curd browning. Maintaining adequate soil moisture, balanced fertilization, and improving soil organic matter through FYM or compost further enhances boron availability and reduces physiological disorders (Marschner, 2012; Barker and Pilbeam, 2015).
- ✓ Copper deficiency causes soft bulbs with thin scales in onion. Copper deficiency in onion can be corrected by applying copper fertilizers either through soil or foliar sprays. Soil application of copper sulphate at about 10-20 kg ha⁻¹ is commonly recommended to improve copper availability. Maintaining balanced fertilization and proper soil pH (around 6.0-7.0) also improves micronutrient uptake and prevents the formation of soft bulbs with thin scales (Jones, 2012; Marschner, 2012).
- ✓ Excess sodium or chloride may reduce fruit size but increase soluble solids concentration. Problems caused by excess sodium or chloride can be managed by improving soil and water management practices. The use of good-quality irrigation water and proper drainage helps preve-

nt salt accumulation in the root zone. Periodic leaching of salts through adequate irrigation and application of gypsum in sodic soils helps replace sodium ions and improve soil structure. Incorporation of organic manures such as FYM or compost also improves soil properties and reduces the harmful effects of salinity on fruit development (Brady and Weil, 2017).

Soil Texture and Crop Quality

Soil texture significantly influences root development, water retention and nutrient availability. The texture of the soil on which certain vegetable crops are grown may also affect the postharvest quality. Root crops such as carrot, radish, and beetroot are particularly sensitive to soil physical conditions. Compact soils often cause root forking and stunted growth in crops such as carrot and radish, reducing market quality. Studies have shown that that carrots grown in muck soils contain higher levels of terpenoids responsible for bitter flavor, whereas carrots grown in sandy soils exhibit milder taste and better consumer acceptance (Simon *et al.*, 1982). Additionally, fruits grown in sandy soils may have lower firmness and total soluble solids (TSS) levels. Micronutrient deficiencies are also more common in coarse-textured soils due to greater nutrient leaching (Brady and Weil, 2017).

Irrigation Management and Postharvest Quality

Adequate irrigation is essential for optimal fruit development and quality. Water stress during the growing season can lead to smaller fruits, reduced firmness, and increased susceptibility to

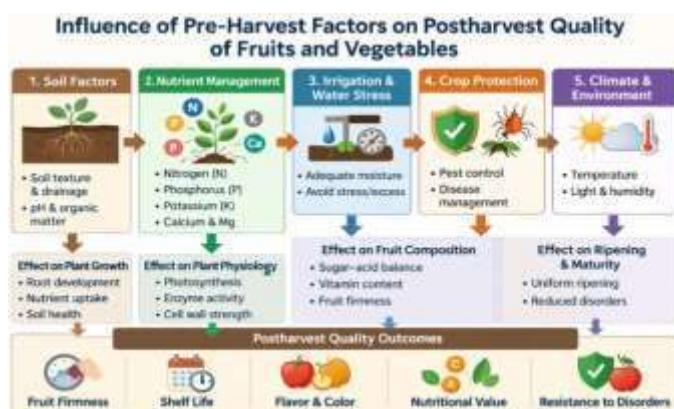
postharvest damage. Severe moisture stress may lead to sunburn in fruits, irregular ripening in pear, and tough texture in peaches. Insufficient irrigation during the growing season may also cause low juice content and thick peel in citrus fruits. Moderate water stress may increase soluble solids, acidity, and vitamin C content, while excessive irrigation leads to softer fruits with reduced shelf life and increased susceptibility to fungal infections (Kirnak *et al.*, 2003). Conversely, excessive irrigation can dilute soluble solids and acids, reducing flavor and nutritional quality. Excess moisture during the growing season may also cause fruit cracking in cherries, prunes, and tomatoes, reduce firmness, delay maturity, and increase susceptibility to mechanical damage and postharvest diseases (Kader, 2002). Furthermore, excess surface moisture on harvested produce can promote microbial growth and increase postharvest decay. Therefore, irrigation methods such as surface or subsurface irrigation may be preferable to overhead irrigation in certain situations to reduce moisture on harvested produce. Vegetables harvested in the early morning, during rainy periods, and from poorly ventilated areas can also experience increased postharvest decay.

Crop protection

Effective pest control plays a crucial role in maintaining the post-harvest quality and shelf life of fruits and vegetables. Proper management of insect pests and diseases during crop growth reduces mechanical injuries, blemishes, and infections that often become entry points for microorganisms after harvest. Integrated pest management (IPM) practices help in producing healthy fruits with better appearance, firmness, and nutritional quality. However, excessive or improper use of pesticides may lead to harmful chemical residues on fruits and vegetables, affecting food safety and market acceptance. Therefore, the use of recommended pesticides at appropriate doses and adherence to pre-harvest intervals are essential to ensure both fruit quality and consumer safety (Food and Agriculture Organization, 2006; Indian Council of Agricultural Research, 2015).

Climate and Environment

Climatic factors such as temperature, rainfall, humidity, and sunlight also play a major role in determining the post-harvest quality of fruits. High temperatures and excessive rainfall during fruit development can accelerate respiration, increase moisture content, and make fruits more susceptible to microbial spoilage after harvest. Similarly, high humidity conditions favor the growth of fungal pathogens, reducing shelf life. On the other hand, favorable climatic conditions during growth improve fruit size, color development, sugar accumulation, and firmness, which enhance storage life and market



quality. Thus, proper management and harvesting under suitable climatic conditions are important for maintaining good post-harvest quality of fruits (Kader, 2002).

Conclusion

Pre-harvest management practices significantly influence the quality, storage life, and marketability of fruits and vegetables. Soil fertility, balanced nutrient management, irrigation scheduling and soil texture play critical roles in determining the physiological and biochemical characteristics of horticultural produce. Adoption of proper pre-harvest management practices can reduce postharvest losses, improve produce quality, and enhance the efficiency of horticultural supply chains. Integrating soil health management, balanced fertilization, and efficient irrigation practices with modern postharvest technologies is essential for sustainable horticultural production.

References

- Barker, A. V. and Pilbeam, D. J. (2015). *Handbook of Plant Nutrition*. CRC Press.
- Brady, N. C. and Weil, R. R. (2017). *The Nature and Properties of Soils*. Pearson.
- Dorais, M., Papadopoulos, A. P. and Gosselin, A. (2001). Influence of nitrogen fertilization on tomato fruit quality. *Acta Horticulturae*, 559: 465-472.
- FAO. (2006). *Plant Nutrition for Food Security*. Food and Agriculture Organization.
- ICAR. (2015). *Handbook of Horticulture*. Indian Council of Agricultural Research.
- Jones, J. B. (2012). *Plant Nutrition and Soil Fertility Manual*. CRC Press.
- Kader, A. A. (2002). *Postharvest Technology of Horticultural Crops*. University of California.
- Kirnak, H., Higgs, D. and Kaya, C. (2003). Effects of irrigation on strawberry yield and quality. *Journal of Plant Nutrition*, 26: 569-584.
- Lester, G. E., Jifon, J. L. and Makus, D. J. (2010). Impact of potassium nutrition on fruit quality of melon and other horticultural crops. *HortScience*, 45(2): 181-185.
- Marschner, P. (2012). *Marschner's Mineral Nutrition of Higher Plants*. Academic Press.
- Nanda, S. K., Vishwakarma, R. K., Bathla, H. V. L., Rai, A. and Chandra, P. (2012). Harvest and post-harvest losses of major crops in India. ICAR.
- Saltveit, M. E. (2005). Postharvest biology and handling. In *Horticultural Reviews* (Vol. 31). Wiley.
- Simon, P. W., Peterson, C. E. and Lindsay, R. C. (1982). Genotype and soil effects on carrot flavor. *Journal of the American Society for Horticultural Science*, 107: 644-648.
- White, P. J. and Broadley, M. R. (2003). Calcium in plants. *Annals of Botany*, 92: 487-511.
- Wills, R., McGlasson, B., Graham, D. and Joyce, D. (2016). *Postharvest: An Introduction to the Physiology and Handling of Fruit and Vegetables* (6th ed.). CABI.

Role of Cytokinin & Its Mode of Action

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Introduction

Cytokinin's are the plant growth regulators that are primarily involved in performing cellular division in plant root and shoot systems. The process helps in increasing the cell's growth, cell development and differentiation, affecting apical dominance, leaf senescence, and axillary bud growth.

Discovery of Cytokinin

F. Skoog and co-workers observed that from the internodal segments of tobacco stems the callus (a mass of undifferentiated cells) proliferated, and the auxin, the nutrient medium, was supplemented with one of the following: extracts of vascular tissues, yeast extract, coconut milk, or DNA.

- ✓ The first synthetic cytokinin was discovered by Miller. It is called kinetin (6-furfuryl amino-purine). It is a synthetic cytokinin that was obtained from autoclaved herring sperm DNA.
- ✓ The first natural cytokinin was discovered by Lethan. It is known as zeatin (6-hydroxy, 3-methyl, trans-2-butenyl amino purine). It is obtained from unripe maize grains and coconut milk.
- ✓ 6-benzyl amino purine, or BAP, is the first-generation synthetic cytokinin. Other examples of synthetic cytokinin are diphenylurea and thidiazuron (TDZ).

Functions

- ✓ Cell division is essential for cytokinesis, though chromosome doubling can occur in its absence. Cell division in callus requires both the hormone auxin and cytokinin.
- ✓ It also causes cell elongation.
- ✓ It induces the formation of chloroplasts, lateral shoots, and adventitious shoot formation.
- ✓ For morphogenesis or differentiation of tissue and organs, plants require both auxin and cytokinin hormones. Buds develop when cytokinin is present in excess as compared to auxin, while roots are formed when this ratio is reversed.
 - ✚ High cytokinin/ auxin ratios favor the formation of shoots while, low cytokinin/ auxin ratios favor the formation of roots.
 - ✚ Intermediate cytokinin/ auxin ratios callus formation
- ✓ Cytokinins act antagonistically to auxin. Auxin promotes apical dominance, whereas it suppresses apical dominance. Thus, when cytokinin is applied to lateral buds, it helps in their growth despite the presence of an apical bud.
- ✓ It shows the Richmond-Lang effect, which means it delays the senescence of leaves and other organs by mobilizing nutrients toward them
- ✓ Cytokinin increases disease resistance and high-

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and low-temperature resistance in plants.

- ✓ They overcome seed dormancy.
- ✓ They induce femaleness in flowers and salt accumulation in cells.
- ✓ They can induce parthenocarpy in plants. It was reported by Crane in 1965.

Cytokinin Biosynthesis, Transport and Signaling

- ✓ Cytokinins (CKs) are plant hormones that mainly help plants grow by making cells divide. There are different forms of CKs, like the inactive ones (tZ-riboside and iP-riboside) and the active ones (such as isopentenyltransferase IPT, trans-zeatin tZ, cis-zeatin cZ, and dihydrozeatin DZ).
- ✓ The production of cytokinin starts when an enzyme called IPT adds a special chemical group to molecules like AMP, ADP, or ATP. Some IPT types, called tRNA-IPTs, make the cZ-type CK and are always active in the plant, acting as housekeeping molecules.
- ✓ Other IPTs are more active in specific tissues but reduce their activity when the plant faces stress. The inactive CK molecules (like isopentenyl adenosine nucleotides) are then changed into active forms (like tZ) by enzymes called CYP735A1 and CYP735A2.
- ✓ Another enzyme called LOG (LONELY GUY) finishes the activation by turning these inactive forms into active hormone forms that the plant can use. CK levels are controlled by enzymes called CK oxidases/dehydrogenases (CKXs), which break down active CK but do not affect some forms like dihydrozeatin or synthetic CKs.

- ✓ CKs are made in roots and shoots and move between these parts and neighboring cells with the help of special transport proteins. Some transporters bring CK inside cells (influx), while others pump it out (efflux) to move it around long distances in the plant. When CK binds to special receptor proteins (AHKs) in the cell, it starts a chain reaction inside the cell involving proteins called AHPs and ARR2s, which then activate genes that respond to CK.
- ✓ There are two types of ARR2s: type-B that promote gene activation and type-A that block the signal by competing with type-B.

Conclusion

Integrating cytokinins into vegetable crop management offers a proactive path to higher yields, improved quality, enhanced resilience to stress, and extended harvest periods. Thoughtful use of cytokinin-based interventions allows growers to elevate crop performance and contribute to sustainable vegetable production.

References

- Liu, Y., Zhang, M., Meng, Z., Wang, B. and Chen, M. (2020). Research progress on the roles of cytokinin in plant response to stress. *International Journal of Molecular Sciences*, 21(18): 6574.
- Ioio, R. D., Linhares, F. S. and Sabatini, S. (2008). The study highlights the emerging role of cytokinin as a regulator of cellular differentiation. *Current Opinion in Plant Biology*, 11(1): 23-27.

Forest to Plate: The Nutritional Richness of Lingura (*Diplazium esculentum*) An Edible Fern

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Introduction

The availability, accessibility and sustainability of nutritional food is most important to meet out the food security, the vegetable fern is a common, edible and nutrient rich fern available in tropical and subtropical forest of India. *Diplazium esculentum* has common name like paco fern, lingura, kombda and pucuk paku, In Himachal Pradesh it was referred as linguda and mostly grown in the forest region. Lingura is commonly used for treating wounds, infection, digestive problems and fever. It is wild stable vegetables in Asia and mostly recognized for its pharmacological properties like antimicrobial and antioxidant effects, it has bioactive compounds like flavonoids, alkaloids, tannins, saponins, phenolic compounds, terpenoids, anti-oxidant, anti-microbial, anti-inflammatory, anti-diabetic, hepatoprotective and neuroprotective activities.

Ethanomedical Property: The various research validating its medicinal potential like anti-oxidant and free radical scavenging activity, it will overcome from the oxidative stress using through high concentration of flavonoids, quercetin, phenolic compounds from the ethanol extract of *D. esculentum*. anti-inflammatory and analgesic activity and Anti-diabetic property this ethanolic extract can reduce blood sugar level in animals.

Anthelmintic potential of this plant act as dewormer the extract paralyze and kill the intestinal parasite. Alzheimer's disease can be prevented by the ethanol extract of lingura.

Phytoconstituents: *D. esculentum* have different group of phytochemicals like, anthraquinones, alkaloids, flavonoids, anthranol glycosides, phenolic compounds, phytosterols, saponins, steroids, tannins, glycosides, cyanidins, leucoanthocyanins, cardiac glycosides and terpenoids which are commercially used in paracentral industries.

Antioxidant and Free Radical Scavenging Activities



The methanolic activity are high in DPPH radical scavenging, *D. esculentum* is a strong iron chelator, sometime plant shows reducing power when exceed the standard antioxidants, like ascorbic acid it will protect the cellular membranes through inhibiting lipids peroxidation of plant extract, efficiency in scavenging nitric oxide, hydroxyl radicals and superoxide. The plant possesses efficient hypochlorous acid scavenging activity.

Antidiabetic Activity: The anti-diabetic activity and

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medicinal properties activated by the active constituent of *D. esculentum* with rich sources of phytochemical such as flavonoids, phenols, minerals and bioactive compounds which contains protein, fiber, and carbohydrates. It has hypoglycemic effect in the extracts from leaf and fronds of *D. esculentum* which lower blood glucose levels, due to high anti-oxidant activity which reduce the oxidative stress also supports by reducing the organ damage due to diabetics.

Antibacterial Activity: The antibacterial activity is contributed with phytochemicals like saponin, terpenoids, steroids, flavonoids and phenols. Aqueous extract from the rhizome and root of the *Diplazium esculentum* inhibits the bacterial growth, but the leaf extract doesn't show any inhibition of bacteria, the root extract has synergistic effect was applied with the antibiotic activity against salmonella arizonae and staphylococcus aureus. There is no inhibition against *E. coli* from extract of leaf and root. *D. esculentum* has strong antimicrobial activity against some microbes, the highest zone of inhibition was seen against *sarcina lutea* and *salmonella typhimurium*. The aqueous extract has highest zone of inhibition was found in salmonella typhimurium.

Anti-Helminthic Activity: The anti-helminthic potential compounds are flavonoid, tannins, and saponins which could responsible for the anti-helminthic and potential anti-parasite. Anti-helminthic activity of aqueous extract from root and rhizome of *Diplazium esculentum* like ethanolic and

petroleum ether extract, this showed paralyzing and mortality effect on worms, depend upon the does this may gradually leads to death.

Hepatoprotective Activity: Hepatoprotective activity potential compounds like phenolic, tannin, saponins and flavonoids. Induced toxicity through carbon tetrachloride (CCI₄) pretreating with *D. esculentum* extract shows increase in cell viability up to 84%. Mechanism like neutralizing free radicals, the evident of research that aqueous leaf extract protect against the chloroform induced liver damage in albino rats. This also traditionally used for treating ailment and liver related problems.

Cytotoxic Activity: The cytotoxic activity potential attributed in rich sources of polyphenols and flavonoids content. There is less cytotoxicity to the normal cells and potential antitumor, anti-inflammatory and anti-oxidant property. This fern leaf extract shows toxicity on brine shrimp lethality bioassay; this observed through both chloroform and methanol extract which increases in concentration and percent of mortality of the shrimp increases. The ethanolic extract of *D. esculentum* does not inhibit the proliferation of cell line like MDA-MB-231, MCF7, Caco-2 and HepG2.

Immunomodulatory Activity: *D. esculentum* shows the effectiveness in loss of body weight and spleen weight through up take of boiled fern in fed Swiss albino rat, it indicates immunosuppressive potential. This aqueous and ethanolic extract is tested for anti-anaphylactic and mast cell stabilizing activity, both the extract showed anti-anaphylactic

activity by reducing mast cell. The observation was that pretreatment of rat with *D. esculentum* extract will stabilize the mast cell membrane.

References

- Amit, S., Sunil, K. and Arvind, N. (2011). Anti-bacterial activity of *Diplazium esculentum* (Retz.) Sw. *Pharmacognosy Journal*, 3(21): 77-79.
- Roy, S. and Chaudhuri, T. K. (2017). Toxicological assessment of *Diplazium esculentum* on the reproductive functions of male Swiss albino mouse. *Drug and Chemical Toxicology*, 40(2): 171-182.
- Zannah, F., Amin, M., Suwono, H. and Lukiati, B. (2022). Identification of metabolite compounds and biological activity of *Diplazium esculentum*. *International Journal Bio Automation*, 26(2): 131-140.

Integrated Nutrient Management for Sustainable Baby Corn (*Zea mays* L.) Production

Durgvijay Yadav and Arun Alfred David

Abstract

Baby corn (*Zea mays* L.) is emerging as an important high-value vegetable crop due to its short duration, high nutritional quality, and increasing market demand in both domestic and international markets. The crop is harvested at an immature stage before pollination, which allows farmers to obtain rapid economic returns and integrate it easily into diverse cropping systems. However, intensive cultivation practices and excessive reliance on chemical fertilizers often lead to soil nutrient imbalance, decline in soil organic matter, and deterioration of soil health. Integrated Nutrient Management (INM) has been widely recognized as an effective approach to maintain soil fertility while enhancing crop productivity. INM involves the combined use of chemical fertilizers, organic manures, and biofertilizers to provide balanced nutrition to crops and improve nutrient use efficiency. Organic sources such as farmyard manure contribute organic matter to soil, improve soil structure, and enhance microbial activity. Biofertilizers promote nutrient availability through biological processes including nitrogen fixation and phosphate solubilization. The integration of these nutrient sources ensures efficient nutrient cycling and sustainable crop production. Several studies have reported that the adoption of INM practices significantly improves baby corn growth, yield, and soil health. Therefore, integrated nutrient management plays a vital role in achieving sustainable baby corn production while conserving soil resources for future generations.

Introduction

Baby corn is the immature ear of maize harvested before fertilization, generally within two to three days after silk emergence. Due to its tender texture, pleasant taste, and high nutritional value, baby corn is widely used in salads, soups, stir-fried dishes, and processed food products. The crop has gained considerable importance in recent years because of its high market demand and potential for generating additional income for farmers.

Baby corn cultivation provides several advantages compared with traditional maize production. The crop has a short growth period, allows multiple harvests, and can be integrated into different cropping systems. Additionally, baby corn production generates green fodder as a by-product, which can be used for livestock feeding. Despite these advantages, continuous cultivation and excessive use of chemical fertilizers have led to several environmental and soil-related problems.

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Long-term application of chemical fertilizers without organic inputs may reduce soil organic carbon content, disrupt soil microbial activity, and lead to nutrient imbalance. These issues ultimately affect crop productivity and sustainability.

Concept of Integrated Nutrient Management

Integrated Nutrient Management refers to the systematic and balanced use of different nutrient sources to achieve sustainable agricultural production while maintaining soil fertility. Chemical fertilizers provide essential macronutrients such as nitrogen, phosphorus, and potassium required for plant growth. However, excessive dependence on chemical fertilizers can deteriorate soil health. Therefore, combining inorganic fertilizers with organic and biological nutrient sources is essential for sustainable agriculture.

Role of Organic manures in baby corn production

Organic manures such as farmyard manure, compost, and green manure play an important role in improving soil fertility. These organic inputs enhance soil structure, increase water holding capacity, and improve microbial activity in the soil. Organic manures also serve as a slow-release source of nutrients and help maintain soil organic carbon levels.

Role of Biofertilizers in Nutrient Management

Biofertilizers are beneficial microorganisms that enhance nutrient availability through biological processes. Nitrogen-fixing bacteria such as *Azotobacter* and *Azospirillum* convert atmospheric nitrogen into plant-available forms. Similarly, phos-

phate-solubilizing bacteria help in converting insoluble phosphorus into soluble forms. These microorganisms also stimulate plant growth by producing growth-promoting substances and improving root development.

Effect of Integrated Nutrient Management on Soil Health

Integrated nutrient management significantly improves soil physical, chemical, and biological properties. The addition of organic matter increases soil organic carbon content and enhances microbial activity. Improved microbial activity supports nutrient cycling, decomposition of organic matter, and overall soil fertility. Long-term application of INM practices has been shown to improve soil structure and maintain sustainable crop production.

Role of Different Nutrient Sources in Integrated Nutrient Management

Nutrient Source	Major Function	Benefit in Baby Corn Production
Chemical fertilizers	Supply essential nutrients	Rapid plant growth and yield
Farmyard manure	Adds organic matter	Improves soil structure and microbial activity
Biofertilizers	Biological nutrient transformation	Enhances nutrient availability
Compost	Slow nutrient release	Improves soil fertility

Impact of INM on Baby Corn Productivity

The combined use of chemical fertilizers, organic manures, and biofertilizers ensures balanced nutrient supply and improves nutrient use efficiency. As a result, baby corn plants exhibit improved growth, higher biomass production, and increased yield. Integrated nutrient management also reduces nutrient losses and promotes sustainable crop produ-

ction systems.

Conclusion

Integrated nutrient management is an environmentally sustainable approach for improving baby corn productivity while maintaining soil fertility. The combined use of chemical fertilizers, organic manures, and biofertilizers ensures balanced nutrient supply, enhances nutrient use efficiency, and improves soil health. Therefore, INM should be promoted as an essential strategy for sustainable baby corn cultivation.



Power of Indoor Plants: Breathe Better, Live Greener

Shruthi H. R. and R. Girish

Humans are dependent upon plants, but modern houses and urban communities disconnect us from nature, thus prompting anxiety and poor mental health. However, most of these problems can quickly be managed by introducing indoor plants in our living space. Indoor plants are ornamental plants grown inside house, office, buildings for decoration, air purification and to bring nature indoors. These ornamental plants are cultivated indoors for their ability to grow in low light with minimal maintenance and at the same time they offer wide variety of scientifically proven effects. Here is the list of top benefits of houseplants

Purify air: Indoor plants are improving indoor air quality as they absorb toxins and pollutants from the air. They act as natural air purifiers, absorbing harmful pollutants like carbon monoxide, formaldehyde, ammonia and pollen, while releasing oxygen. We live in apartments with low ventilation and we breathe polluted air throughout the day and night. But plants help purify the air. On an average 6 to 8 medium to large sized indoor plants in a room can improve air quality.



release oxygen during photosynthesis, but at the same time they release water vapors in the air. These vapors thus increase humidity creating a



micro climate indoor. This not only makes your space more eco-friendly but also more cost-efficient.

Great home décor: Besides providing health benefits, the benefits of houseplants are also aesthetic as they create an excellent home décor.

Promote improved sleep: Higher level of oxygen in air promotes brain to remain deep, restorative sleep. Adding a plant near bed would be a great idea, as plants absorb carbon dioxide and other pollutants.

Reduce noise pollution: Plants reduce noise pollution by reducing, reflecting and deflecting sound. Ever wondered why forests are so silent? The presence of numerous plants and trees is the prominent reason behind this. If we live in a busy roads, by placing or planting large plants at balcony or entrance of house to experience noticeable changes in noise pollution.



Increase indoor humidity: We all know Plants

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Exploiting Wild Cucurbit Diversity for Sustainable Improvement of Cucurbit Crops under Biotic and Abiotic Stresses

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Abstract

Cucurbitaceous vegetables play an important role in human nutrition and agricultural production across tropical and subtropical regions. However, cucurbit crops frequently face several biotic and abiotic stresses that significantly reduce yield and quality. Wild cucurbit species represent valuable genetic resources that possess natural resistance and tolerance to pests, diseases, drought, salinity, and high temperatures. These wild relatives serve as important donors of beneficial genes for crop improvement programs. The utilization of wild cucurbit germplasm through breeding, hybridization, and grafting techniques can enhance stress tolerance and productivity in cultivated varieties. This review highlights the importance of wild cucurbit species, their resistant characteristics, and their potential use in cucurbit breeding programs for sustainable vegetable production.

Introduction

Vegetables are an essential component of human nutrition as they provide vitamins, minerals, fibre, and antioxidants. Among vegetable crops, the family Cucurbitaceae occupies an important position due to its wide cultivation and economic significance. The cucurbit family consists of approximately 95 genera and nearly 950 species, many of which are cultivated as vegetables and fruits such as cucumber, melon, pumpkin, bitter gourd, bottle gourd, and watermelon. Cucurbit crops are widely grown in tropical and subtropical regions of the world and contribute significantly to food security and agricultural income. In India, cucurbitaceous vegetables are cultivated extensively due to their

adaptability, short duration, and high productivity. Despite their importance, cucurbit crops are highly susceptible to several biotic stresses, including insect pests, fungal diseases, bacterial infections, and viral diseases. In addition, abiotic stresses such as drought, salinity, heat stress, and nutrient deficiencies can severely limit crop productivity. Wild relatives of cultivated crops are considered important reservoirs of genetic diversity and stress tolerance traits. Wild cucurbit species possess many desirable traits such as resistance to pests and diseases, tolerance to environmental stresses, and adaptability to harsh growing conditions. Therefore, they play a crucial role in cucurbit breeding programs aimed at improving yield stability and climate resili-

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ence.

Importance of Wild Cucurbit Species

Wild cucurbit species are important sources of genetic variation that can be used to improve cultivated cucurbit crops. Unlike cultivated varieties that have undergone selection for yield and quality, wild species have evolved under natural environmental conditions and therefore possess strong adaptive traits. These species often exhibit tolerance to drought, resistance to pests and diseases, and adaptability to marginal soils. The genes responsible for these traits can be transferred to cultivated crops through plant breeding techniques such as hybridization, backcrossing, and molecular breeding. Wild cucurbits are also important for maintaining biodiversity and ecological stability. Conservation of wild relatives ensures the availability of genetic resources for future crop improvement programs. Another important use of wild cucurbits is in rootstock breeding for grafting. Grafting cultivated cucurbit plants onto resistant rootstocks improves plant vigour, nutrient uptake, and resistance to soil-borne diseases.

Biotic Stress Resistance in Wild Cucurbits

Biotic stresses caused by insects, pathogens, and viruses are major constraints in cucurbit production. Wild cucurbit species have developed natural resistance mechanisms to protect themselves from these stresses. *Cucumis hardwickii*, a wild relative of cucumber, has shown resistance to powdery mildew and downy mildew, two major fungal diseases affecting cucurbits.

Similarly, *Momordica charantia* var. *muricata* has been reported to possess resistance to fruit fly infestation and viral diseases, which are serious problems in bitter melon cultivation. Wild forms of *Lagenaria siceraria* exhibit tolerance to soil-borne pathogens such as Fusarium wilt, making them useful as rootstocks in cucurbit grafting (Lee *et al.*, 2010). Another important species is *Cucurbita foetidissima*, which has shown resistance to root-knot nematodes, an important pest affecting cucurbit crops world-wide.

Abiotic Stress Tolerance in Wild Cucurbits

Abiotic stresses such as drought, salinity, and extreme temperatures significantly affect cucurbit production. Wild cucurbit species often grow in harsh environments and have developed mechanisms to tolerate such conditions. *Citrullus colocynthis*, a wild relative of watermelon, is highly tolerant to drought, salinity, and high temperature conditions. It grows naturally in desert and semi-arid environments and is considered an important genetic resource for improving watermelon tolerance to environmental stresses. Similarly, *Cucurbita foetidissima* shows strong drought tolerance due to its extensive root system and ability to survive in dry environments. Wild bottle gourd types (*Lagenaria siceraria*) have also shown tolerance to salinity and soil-borne stresses, making them useful rootstocks in cucurbit grafting systems. The utilization of genes from wild cucurbit species can significantly enhance the resilience of cultivated crops under adverse environmental conditions.

Role of Wild Cucurbits in Breeding Programs

Wild cucurbit species are valuable resources in breeding programs aimed at developing improved varieties. Traditional breeding methods such as hybridization and backcrossing are used to transfer beneficial genes from wild species into cultivated varieties. Modern technologies such as marker-assisted selection, genomic studies and biotechnology tools have further enhanced the efficiency of using wild germplasm in breeding programs. Wild cucurbit species are also widely used as rootstocks in grafting, which improves plant vigour, disease resistance, and yield. The conservation of wild cucurbit germplasm through gene banks, botanical gardens, and in-situ conservation programs is essential to ensure their availability for future crop improvement efforts.

Future Prospects

The importance of wild cucurbit species is expected to increase with the growing challenges of climate change, emerging pests, and limited natural resources. Advances in genomics, molecular breeding, and biotechnology will facilitate the identification and transfer of stress-tolerance genes from wild species to cultivated crops. Exploration, characterization, and conservation of wild cucurbit germplasm will play a crucial role in developing climate-resilient cucurbit varieties for sustainable agriculture.

Conclusion

Wild cucurbit species are valuable genetic resources that possess numerous beneficial traits

such as resistance to pests and diseases, tolerance to drought and salinity, and adaptability to harsh environmental conditions. These traits can be utilized in breeding programs to develop improved cucurbit varieties with enhanced productivity and resilience. Conservation and utilization of wild cucurbit germplasm are essential for sustainable cucurbit production and future food security.

References

- Grumet, R., McCreight, J. D., McGregor, C., Weng, Y., Mazourek, M., Reitsma, K., ... and Fei, Z. (2021). Genetic resources and vulnerabilities of major cucurbit crops. *Genes*, 12(8): 1222.
- Khoury, C. K., Carver, D., Kates, H. R., Achicanoy, H. A., van Zonneveld, M., Thomas, E., ... and Greene, S. L. (2020). Distributions, conservation status and abiotic stress tolerance potential of wild cucurbits (*Cucurbita L.*). *Plants, People, Planet*, 2(3): 269-283.
- Ranjan, J. K., Pandey, S., Prgaya, Akhter Ansari, W., Krishna, R., Tarique Zeyad, M. and Singh, V. (2022). Biotic stresses in cucurbits: Status, challenges, breeding and genetic tools to enhance resistance. In *Genomic Designing for Biotic Stress Resistant Vegetable Crops* (pp. 345-379). Cham: Springer International Publishing.

Pumpkin (*Cucurbita spp.*) as a Functional Food: Nutritional Composition, Bioactive Compounds and Health-Promoting Properties

Saranya R., R. Niranjana, K. Lakshanya, M. Shamini and T. Ilakiya

Introduction

Pumpkin (*Cucurbita spp.*) is an important vegetable crop belonging to the family Cucurbitaceae. It is believed to have originated in Central and South America, but today it is widely cultivated across the world in both tropical and temperate regions. Pumpkin can grow in a wide range of environments, from sea level to higher altitudes. Many countries cultivate pumpkin as an important vegetable crop, and India, China, Mexico and the United States are among the major producers globally. Several species of pumpkin are cultivated, among which *Cucurbita pepo*, *Cucurbita maxima*, and *Cucurbita moschata* are the most commonly grown. Pumpkin is valued not only for its culinary uses but also for its nutritional and medicinal properties. The fruit is used in the preparation of various food products such as juices, purees, pickles, baked goods and dried products. Due to its rich nutritional composition, pumpkin has gained attention as a functional food that can contribute to better health and nutrition. Pumpkin contains a wide

range of essential nutrients including vitamins, minerals, carbohydrates and dietary fiber. It is particularly rich in β -carotene, a precursor of vitamin A, which is important for maintaining eye health and proper immune function. In addition, pumpkin provides vitamins such as vitamin B₆, vitamin K, thiamine and riboflavin. It also contains essential minerals including potassium, phosphorus, magnesium, iron and selenium. Pumpkin seeds are also highly nutritious and contain significant amounts of proteins, healthy oils and important minerals such as calcium, magnesium, zinc, copper and manganese. Because of these nutrients and bioactive compounds, pumpkin is associated with several health benefits including antioxidant, anti-inflammatory and disease-preventing properties.

Nutritional Components of Pumpkin

Pumpkin is considered a nutrient-rich vegetable that contributes significantly to human nutrition. One of its most important components is provitamin A carotenoids. These carotenoids are responsible for the characteristic yellow or orange

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colour of the pumpkin fruit. Among them, β -carotene is the most abundant and plays a vital role in human health. Inside the body, β -carotene is converted into vitamin A, which is essential for vision, growth, and proper development. Deficiency of vitamin A can lead to various health problems, including impaired vision and weakened immunity. Pumpkin fruit mainly consists of pulp and seeds, both of which contribute to its nutritional value. Pumpkin seeds are especially rich in nutrients and provide high amounts of protein, oil, dietary fibre, and minerals. Studies have shown that pumpkin seeds contain approximately 39% protein and around 27% oil on a dry weight basis. In addition, they contain significant levels of dietary fibre and provide a high amount of energy. Pumpkin seeds also contain several important minerals, including potassium, calcium, magnesium, zinc, and iron, which play crucial roles in maintaining various physiological functions in the human body. Another important feature of pumpkin seeds is the presence of essential and non-essential amino acids. Among the essential amino acids, lysine is present in relatively higher quantities, while glutamic acid is the most abundant non-essential amino acid. These amino acids are necessary for the proper functioning of the body and help support tissue growth and repair. The pulp of pumpkin also contributes to its nutritional value. Although it contains relatively low fat content, it provides moderate amounts of carbohydrates and small quantities of protein. Pumpkin pulp also contains valuable nutrients such as vitamin C and vitamin E.

Vitamin C helps strengthen the immune system and acts as an antioxidant, while vitamin E protects cells from oxidative damage. The presence of these vitamins and phytochemicals makes pumpkin an important food for maintaining overall health.

Nutraceutical Properties of Pumpkin

Antioxidant Activity: Pumpkin is recognized as a good source of antioxidant compounds that help protect the body from oxidative stress. Oxidative stress occurs when harmful free radicals accumulate in the body and damage cells. The carotenoids and tocopherols present in pumpkin act as natural antioxidants and help neutralize these free radicals. Pumpkin seed oil contains tocopherols, which belong to the vitamin E group of compounds. These compounds play an important role in protecting cellular components from oxidative damage. As a result, regular consumption of pumpkin and its seed products may contribute to improved health and reduced risk of chronic diseases.

Hypotensive Activity: Pumpkin has also been reported to have beneficial effects on cardiovascular health. The high magnesium content present in pumpkin may help regulate blood pressure levels. Magnesium plays an important role in maintaining normal heart function and proper blood circulation.

Antidiabetic Activity: Pumpkin has shown promising effects in the management of diabetes. Diabetes mellitus is a chronic metabolic disorder characterized by elevated blood glucose levels due to insufficient insulin production or reduced insulin sensitivity. Certain bioactive compounds present in

pumpkin seeds, particularly tocopherols, exhibit antioxidant properties that may help improve glucose metabolism. Research studies have indicated that pumpkin fruit and seed extracts may help regulate blood sugar levels and improve metabolic health. For this reason, pumpkin is often recommended as a beneficial food component for individuals with diabetes.

Anticancer Activity: Pumpkin also contains compounds that may help reduce the risk of cancer. The carotenoids and polyphenols present in pumpkin are known to regulate abnormal cellular processes that are associated with the development of cancer. These compounds help inhibit inflammation and reduce oxidative stress, which are important factors involved in tumor development. Some studies suggest that diets rich in pumpkin seeds may lower the risk of cancers such as prostate, breast, lung and colon cancer. Pumpkin polysaccharides also contribute to anticancer activity by scavenging harmful reactive oxygen species produced during metabolism.

Antimicrobial Activity: Pumpkin has also demonstrated antimicrobial properties against several pathogenic microorganisms. Extracts obtained from pumpkin leaves, fruits and seeds have shown inhibitory effects against various bacteria and fungi. These include microorganisms such as *Escherichia coli*, *Staphylococcus aureus*, *Klebsiella pneumoniae*, *Pseudomonas aeruginosa* and *Candida albicans*. Because of these antimicrobial properties, pumpkin has gained importance in pharmaceutical and micro-

biological research. Its bioactive compounds may potentially be used in the development of natural antimicrobial agents.

Conclusion

Pumpkin is a highly valuable vegetable crop that provides both nutritional and medicinal benefits. It contains a wide range of vitamins, minerals, antioxidants, and bioactive compounds that contribute to human health. Regular consumption of pumpkin and its seeds can support vision, improve heart health, strengthen immunity, and help prevent several chronic diseases. Due to its rich nutritional composition and therapeutic potential, pumpkin plays an important role in improving nutritional security and promoting overall well-being.

References

- Borecka, M. and Karaś, M. (2025). A comprehensive review of the nutritional and health-promoting properties of edible parts of selected Cucurbitaceae plants. *Foods*, 14(7): 1200.
- Kaur, S., Panghal, A., Garg, M. K., Mann, S., Khatkar, S. K., Sharma, P. and Chhikara, N. (2020). Functional and nutraceutical properties of pumpkin-a review. *Nutrition & Food Science*, 50(2): 384-401.
- Batool, M., Ranjha, M. M. A. N., Roobab, U., Manzoor, M. F., Farooq, U., Nadeem, H. R. and Ibrahim, S. A. (2022). Nutritional value, phytochemical potential, and therapeutic benefits of pumpkin (*Cucurbita sp.*). *Plants*, 11(11): 1394.

Use of Modern Agriculture Technology in Ladakh

Stanzin Idong

Introduction

Ladakh, often referred to as a cold desert, is characterized by its severe winters and limited arable land. These conditions have long hindered agricultural productivity, leaving the region underdeveloped in farming practices. Despite this, over 70% of Ladakh's population depends on agriculture for their livelihood. Unfortunately, the agricultural landscape remains largely traditional, with minimal adoption of modern methods. As a result, even with available land, the region struggles to produce enough food to support its growing population. One of the major challenges faced by Ladakhi farmers is irrigation. Snowmelt irrigation, historically the primary water source, has been drastically affected over the past five years. Winters, which once brought temperatures as low as -40°C and snowfall up to 3-4 feet, have become milder due to global warming, resulting in reduced snowfall. Rainfall, too, is scarce measuring only a few centimeters annually which offers little relief to agriculture. As a resident, I have witnessed how snowmelt once nourished fields from April onward. But now, many areas remain dry. In village like Kulum, water sources have nearly vanished, making farming and daily chores extremely difficult forcing them to leave their forefathers village and settled somewhere else.

Another alarming concern is the depletion of groundwater and natural springs, locally known as “chasma.” Ladakh is renowned for its mineral-rich hot springs, which are also diminishing due to irregular snowfall and lack of groundwater recharge. This environmental shift poses a direct threat to the region's already fragile agricultural system.

To address these challenges, the Department of Agriculture has introduced modern technologies to assess their effectiveness in this unique environment. One such advancement is drip and sprinkler irrigation, technologies that originated in foreign and are now being adopted across India including Ladakh.

Drip Irrigation: This method involves laying small pipes across the fields that release water directly at the plant's roots drop by drop through the holes



Fig 1: Laying of drip pipes to grow apples in farmer's field

minimizing water waste as happens in flood irrigation. While in Ladakh it has proven especially effective for vegetables, fruits, watermelon and muskmelon, and is ideal for areas with limited water Fig. 1. As an agriculture officer, I've seen firsthand how this method benefits farmers, particularly in barren lands where fruit crops are now being cultiva-

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ted successfully using drip irrigation. India has a large area which are barren and considered non-cultivable is now being cultivated with use of this method. It is being provided to farmers at subsidized rate and mobilized among the farmers through training.

Sprinkler Irrigation: In this method, water is sprayed through a long pipe in the air, simulating natural rainfall. It ensures uniform distribution, conserves water, and reduces soil erosion. In Ladakh, it is well-suited for crops like alfalfa and mustard. But its popularity is limited as its usage in Ladakh is limited to above mentioned crops only. Even it is provided to farmers at a subsidy rate.

Mulching: Another promising technology is the use of mulching, especially with black polythene. Mulching refers to covering the ground with materials like straw, dried leaves, or plastic sheets. This helps retain soil moisture, reduces weed growth, and boosts production. In Ladakh, black polythene mulching has gained popularity for growing watermelon, muskmelon, and pumpkin Fig. 2 crops once rare in the region due to climatic constraints. Its ability to retain moisture has made irrigation less frequent, proving to be a game-changer.



Fig. 2: Use of black polythene at department farm

During my childhood, the main crops grown in Ladakh were wheat, barley, and vegetables like cauliflower, cabbage, turnip, and carrot. Today, there has been a noticeable shift towards more diverse and income-generating crops. Over the last five years, agriculture in Ladakh has undergone a positive transformation. Farmers are now more informed, enthusiastic, and open to experimenting with new technologies. In fact, villages like Phey have emerged as success stories, where progressive farmers have grown watermelon using mulching and earned a good income, contributing to financial stability. In several cases both the technologies mulching and drip/sprinkler irrigation are used together to enhance its result. In agriculture farms, crops like summer squash, watermelon and bottlegourd are grown with the above technology. Firstly, number of irrigation reduces, there are little or no interculture practices specially weeding, it maintains the right temperature for crop growth and increases production.

Conclusion

However, the adoption of these modern technologies is still limited due to several barriers. The deep-rooted traditional farming culture makes it difficult to introduce new methods. Many farmers are older, and persuading them to shift from traditional ways is challenging. They believe if they adopt changes it's not a good sign and disturb the very nature. Despite subsidies provided by the UT Government and the Department of Agriculture, certain eligibility requirements make it difficult for

many to benefit from these schemes. Nevertheless, from my experience, I can confidently say that many farmers are beginning to embrace changes. Those who have adopted these technologies are seeing tangible improvements in both yield and income stability. With continued support and awareness, Ladakh's agriculture can move towards a more sustainable and prosperous future.



Importance of ICT for Agriculture Development

D. Kumar, R. S. Mehta, Shiren K., S. C. Meena and Nanad Kumar

GIS (Geographical information system): A geographic information system (GIS) is a type of database containing geographic data (that is, descriptions of phenomena for which location is relevant), combined with software tools for managing, analyzing, and visualizing those data. In a broader sense, one may consider such a system to also include human users and support staff, procedures and workflows, body of knowledge of relevant concepts and methods, and institutional organizations.

Remote Sensing: Remote sensing is the acquisition of information about an object or phenomenon without making physical contact with the object, in contrast to in situ or on-site observation. The term is applied especially to acquiring information about the Earth and other planets. Remote sensing is used in numerous fields, including geography, land surveying and most Earth science disciplines (for example, hydrology, ecology, meteorology, oceanography, glaciology, geology); it also has military, intelligence, commercial, economic, planning, and humanitarian applications, among others.



E-Governance: Electronic governance or e-governance is the application of information technology

for delivering government services, exchange of information, communication transactions, integration of various stand-alone systems between government to citizen (G2C), government-to-business (G2B), government-to-government (G2G), government-to-employees (G2E) as well as back-office processes and interactions within the entire governance framework.^[1] Through e-governance, government services are made available to citizens through IT. The three main target groups that can be distinguished in governance concepts are government, citizens, and businesses/interest groups include training staff and students, helping teachers enter coursework, and assisting in day-to-day running of the system.

Role of ICT in agriculture development

- ✓ Economic development: Application in planning and market information for agriculture procedures.
- ✓ Community Development Applications.
- ✓ Research/Education Applications
- ✓ Small and medium enterprise development
- ✓ New media networks
- ✓ Providing decision support to public administrators for improving planning and monitoring of development programmers.
- ✓ Improve services to citizen, and bring in transparency.

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- ✓ Empower citizens through access to information and knowledge
- ✓ Help in training to improve the functioning of developmental organization and expand employment opportunities.
- ✓ Market
- ✓ Linkage
- ✓ Services
- ✓ Small and median former

Cyber Extension: is a managed virtual learning environment built by Right Reason Technologies (RRT) that is designed to be used as an online extension of a school district in the USA. The system is currently used for homebound students, credit recovery and supplemental coursework, and has been successfully deployed to help students with “school phobia” and students undergoing medical treatment. In addition to being a Virtual Learning Environment, cyber extension is a “Managed Learning Environment” in that one or more RRT employees are assigned as liaison to the client school district. Liaison responsibilities.

Digital Divides

D. Kumar, R. S. Mehta, Shiren K. and S. C. Meena

A divide between English and non-English speaking communities where comprehensible content is available only to a selected few who have knowledge of English. North south divide: Between developed and developing countries.

National level initiative in ICT for Agricultural Development

- ✓ Gyandoot project
- ✓ Warna wired village project
- ✓ Information village project of MSSRF
- ✓ I kisan project of Nagarjana group of companies (Andhra Pradesh)
- ✓ Milk collection centers of dairy cooperative of (AMUL) Gujarat.
- ✓ Tarahoat.com by development alternatives (Uttar Pradesh and Punjab)
- ✓ Land Record computerization (Bhoomi)
- ✓ Knowledge network for grass root innovations - SRISTI (Gujarat)
- ✓ Mahiti Samutra (Karnataka)
- ✓ Centre for alternative agriculture media (CAAM)

Networking system of information

A networking is the means by which computers store and exchange information and resources access either short distance (LAN) or globally (wide area network) making best use of networking technology is about optimum use of business resources, enhancing productivity and effi-

ciency, reducing costs and gaining competitive advantages.

Teleconferencing

The new integrated digital communication system is being used. This technique will add new dimensions of control timing and flexibility to communication. Instead of traveling miles for a meeting conference rooms will be wired and can easily be used to carry visuals.

Advantages

- ✓ Time and cost for traditional day to day communication will thus be reduced.
- ✓ It way for international integration.
- ✓ It supports to provide/ exchange latest agricultural technologies available in different countries for the farming communities.

Two types

- ✓ Audio conferencing
- ✓ Video conferencing

Problems of ICT

- ✓ Infrastructure barrier
- ✓ Illiteracy
- ✓ Poverty
- ✓ Policy hurdles
- ✓ Low people participation
- ✓ Lack of will to implementation
- ✓ Heterogeneous adoption
- ✓ Digital divide

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Prospects of ICT

- ✓ Marketing information
- ✓ Remote sensing
- ✓ DSS
- ✓ Realizing the knowledge potentials
- ✓ Revival of extension organizations
- ✓ Convergence with agricultural extension
- ✓ Meeting the challenges of globalization
- ✓ Online services - information, education training, monitoring, evaluation.
- ✓ E-commerce
- ✓ R-E-F interaction
- ✓ Question - answer service
- ✓ E-governance
- ✓ Up to date information service
- ✓ Database creation
- ✓ Predictive in for diseases, pest, weather
- ✓ Land record facilitation

Technology Parks/Rural Tech Parks

D. Kumar, R. S. Mehta, Shiren K. and S. C. Meena

To promote Agricultural food processing, Industries in clusters in areas where there is predominant production of processible argil/hurt products Quick information dissemination for farmer's school children and general public A place to see and learn latest recommendation of crop cultivation and technologies generates by both public and private institutions.

- ✓ A place to see and study heritage agriculture system and future high tech agriculture. Education and training mechanism for village level extension workers as face to face training of widely dispersed large number is practically impossible task.
- ✓ Establishment of live agriculture crop museum
- ✓ Information network among agriculture officers, government and agriculture institutes
- ✓ Aesthetically beautiful landscaping.
- ✓ A site for eco tourism/Agro tourism
- ✓ Generation of funds within the system for its sustainability say sustainer
- ✓ One stop shop - sale centre for plants, seeds and other products of government institution and the private sector entrepreneurs of instructional media material information centre etc.

Main elements of A Parks/T. Parks

- ✓ Venue: Should be at the site of majority of argil related institution.

- ✓ Main sections and presentations rice, section, vegetable garden, roots and labor garden, fruit garden, dry zone crops garden.
- ✓ Exhibition stalls or main crop categories
- ✓ Nursery for demonstration and sales
- ✓ Mushroom house
- ✓ Food tech. demonstration
- ✓ Floriculture demonstration and sales area for private sector
- ✓ A site to demonstrate traditions/indigenous agriculture in India - again agriculture.
- ✓ A site to demonstrate future high tech agriculture
- ✓ Area of student for discovery learning
- ✓ Meteorology
- ✓ Animal production and health
- ✓ Export argil crops
- ✓ Sales centre
- ✓ Information centre
- ✓ Food courts
- ✓ Resting areas

Policing initiative: Developing of world-class infrastructure for agro food processing industries through establishment of agro food tech parks. These are of the state technology furnished locations wait provide info, being, R & D and other services related to new Agriculture and Horticulture forms which are located within the radius of 80.100 Km from the proposed food agro technology parks would be

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linked to these parks. One of the major thrust given by of India for development of world infrastructure for Agro food industries is establishment of “Agro Food Technology Parks” for which financial assistance of Rs 4 Core per park is available from GOI. Common facilities and infrastruce: R & D were housing, cold storage, quality assurance labs, and common effluent treatment plants.



ATIC: Agriculture Technology Information Centre

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The ATIC is a “single window” support system linking the various units of a research institution with intermediary users and end users (farmers) in decision making and problem solving exercise.

The rationale for establishment of ATIC are

- ✓ To provide diagnostic service for soil and water testing, plant and livestock health.
- ✓ To supply research products such as seeds and other planting materials.
- ✓ Providing information through published literature and communication material.
- ✓ Providing an opportunity to the institutes, SAUS to generate some resources through the sale of their technologies.

The important criteria for agriculture technology information are

- ✓ Availability of new technologies
- ✓ Relevance of new tech.
- ✓ Responsiveness of new technologies
- ✓ Sustainability of such unit within the overall institutional system.

Target/users of info

Beneficiaries of ATIC

- ✓ Farmers
- ✓ Farmers - entrepreneurs
- ✓ Extension workers and development
- ✓ NGO's and

- ✓ Private sector organizations

Objectives

- ✓ To provide a single window delivery for producers and services.
- ✓ To facilitate/dissect the farmers access to the institutional resources.
- ✓ To provide mechanism for feedback from the users to the institute.

The information services and supply include

- ✓ Soil and water sample testing facility.
- ✓ Plant clinic and diagnostic centre.
- ✓ Rhizobium culture.
- ✓ IPM - organic and biopesticide/NPY
- ✓ Seed and planting material, small implements
- ✓ Fertilizer quality testing
- ✓ Tissue culture and plant materials
- ✓ Farm literature - leaflets, pamphlets, journals
- ✓ Audio, video cassette on crops
- ✓ Video show
- ✓ Processed products - cereals milk, meat job
- ✓ Cafeteria
- ✓ Technology park (display) exhibition
- ✓ Veterinary animal clinical services.
- ✓ Poultry strains, livestock breeds, seed etc.

Key services and functions of the ATIC include: Single Window System: A one-stop center where farmers can access all necessary information, technologies, and inputs. Input Availability: Sale of

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high-quality seeds, vegetable seedlings, planting materials, bio-fertilizers, and farm machinery. Advisory Services: Expert advice on animal husbandry, soil testing, plant health diagnostics, and pest control through in-person visits or phone calls. Information Dissemination: Distribution of publications (books, bulletins), CDs, and access to interactive kiosks to share new agricultural practices. Technological Evaluation: Providing feedback to scientists about field-level agricultural problems.



E-Governance

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E-governance is defined by M Bakes (Bakus, M. 2001), “Application of electronic means in Interaction between government and citizen and between government and business as well as. In internal government options to simplify and improve democratic, government and business aspects of governance. E-governance is about transforming the relationship between governments and their citizens through the use of information technologies”.

Benefits - Direct

- ✓ Faster, easier more convenient service convenience, near to home, more services at one place.
- ✓ Faster processing shorter wait shorter queries at government offices.
- ✓ Less number of trips to government officer.
- ✓ Better interaction environment no harassment.
- ✓ Reduced transport cost.
- ✓ Avoids wage loss for daily wage earners
- ✓ Better quality service.
- ✓ More accurate and legible documents, easy recovery from errors.
- ✓ Lesser corruption increased transparency.
- ✓ Improved access to offices.

Indirect/Derived

- ✓ Improved complaint handling, complaint tracking
- ✓ Introduces transparency in data, decision/actions, rules procedures and performance of government

agencies.

- ✓ Automated processes to take away discretion.
- ✓ Reduced effectiveness in decision making. Entry point for simplification g rules and engineering process.
- ✓ Makes decision traceable takes actions.
- ✓ Builds accountability
- ✓ Documentation to citizens to follow-up.
- ✓ Tracks procedural, human delay
- ✓ Easier to fix responsibility accountability
- ✓ Modularize tasks making outsourcing possible
- ✓ Introduces completion among delivery channels and departments.
- ✓ Standardized documentation of common of objects leads to effective supervision through comparative indicators.
- ✓ Centralizes data for better audit and analysis integration of data across application.

Critical success factors

- ✓ Political will
- ✓ Overall vision and national (e-strategy)
- ✓ Full ownership and support of cto.
- ✓ Effective and appropriate project.
- ✓ Management
- ✓ Access
- ✓ Education of clients
- ✓ Participation of clients
- ✓ Culture

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- ✓ Cooperation and collaboration with private sector.
- ✓ Technology
- ✓ Human Resources
- ✓ Legal framework
- ✓ Finances

Components of E-governance

- ✓ Political
- ✓ Technological
- ✓ Social
- ✓ Cultural
- ✓ Psychological
- ✓ Service

Interaction among/or ecology of E-governance various components

Stages of E governance

Degree of progress made by government towards the ultimate e-governance goal.

- ✓ Presence
- ✓ Interaction
- ✓ Transaction
- ✓ Transformation

According to Layne on lee (2001)

- ✓ Cataloguing
- ✓ Transaction
- ✓ Vertical integration
- ✓ Horizontal integration

E-governance (electronic governance) uses Information and Communication Technologies (ICTs) like the internet and mobile networks to deliver government services, exchange information, and streamline processes. It enhances efficiency,

transparency and accountability, aiming for SMART (Simple, Moral, Accountable, Responsive, Transparent) governance. Key focus areas include G2C (Government to Citizen), G2B (Government to Business), and G2G (Government to Government) services.

Bioremediation of Contamination of Soil

Bharathi K. B., Sunitha M., Supriya S. and Sneha K. B.

Abstract

Soil contamination by hazardous pollutants poses serious risks to ecosystems and human health. Bioremediation is an eco-friendly and sustainable approach that uses microorganisms such as bacteria, fungi, and algae to degrade or detoxify contaminants. Techniques including biostimulation, bioaugmentation, phytoremediation and mycoremediation enhance this process. Recent advancements like nanoparticles and synthetic biology further improve its efficiency. Overall, bioremediation offers a promising solution for restoring contaminated soils and protecting environmental health.

Introduction

The increasing global population has intensified agricultural and industrial activities, leading to excessive use of fertilizers, pesticides, and chemicals. This has resulted in severe soil contamination, loss of beneficial microorganisms, and deterioration of soil health, ultimately affecting ecosystems and human well-being. Additionally, improper disposal of chemicals, antibiotics, and persistent pesticides like DDT has further aggravated environmental pollution. Bioremediation has emerged as an effective strategy to mitigate such contamination. It involves the use of microorganisms, plants, or their enzymes to degrade, transform, or remove harmful pollutants from soil, water, and air. Since its early application in oil spill treatment in the 1960s, bioremediation has gained importance as a sustainable and eco-friendly alternative to conventional remediation methods. Microorganisms possess diverse metabolic pathways that enable them to utilize toxic compounds as

energy sources and convert them into less harmful forms. Their rapid adaptability and the application of genetic engineering and synthetic biology further enhance their efficiency in pollutant degradation. Bioremediation can be carried out either in-situ (at the contamination site) or ex-situ (after removal of contaminated material). Bioremediation is a cost-effective and environmentally sustainable approach that helps restore soil health, reduce pollution and promote ecosystem resilience. It is widely used in treating industrial contaminants, heavy metals and wastewater, making it a promising solution for environmental restoration.

Strategies for Bioremediation of Contaminated Soil

Bioremediation employs various strategies to enhance the degradation of pollutants in soil. Biostimulation improves the activity of native microorganisms by adding nutrients and oxygen. Bioaugmentation involves introducing specific pollutant-degrading microbes to accelerate remediat-

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ion. Phytoremediation utilizes plants to remove, stabilize or degrade contaminants through mechanisms such as phytoextraction and rhizodegradation. Mycoremediation uses fungi to break down complex pollutants and accumulate heavy metals. Other important techniques include landfarming, which enhances microbial degradation through soil aeration and nutrient addition; bioventing, which supplies oxygen to stimulate aerobic microbes; and biopiles, where contaminated soil is treated in controlled piles. Advanced approaches such as electro-bioremediation, biochar amendment and bio-surfactants further improve contaminant mobility, bioavailability, and microbial activity, thereby enhancing remediation efficiency.

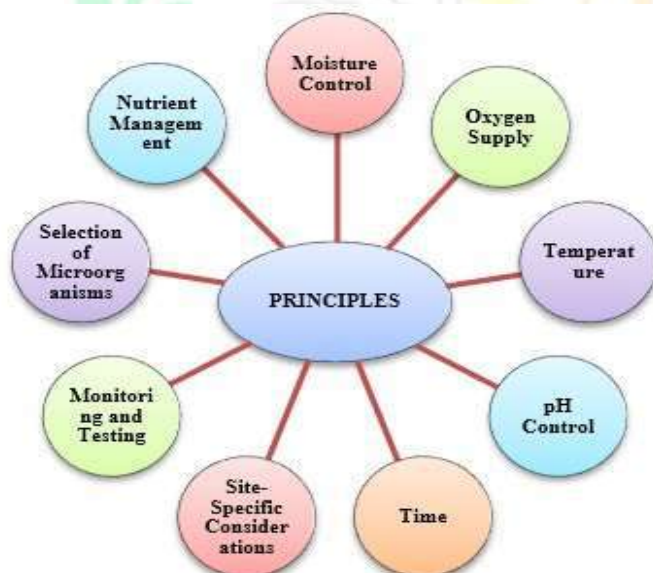


Fig. 1: Principles of bioremediation of contamination of soil

Role of Microorganisms in Bioremediation

Microorganisms play a crucial role in soil bioremediation by degrading, transforming, or immobilizing pollutants. Among them, bacteria are the most significant due to their metabolic versatility.

Species such as *Pseudomonas* and *Bacillus* effectively degrade hydrocarbons, pesticides, and industrial chemicals. However, degradation may sometimes produce intermediate compounds that are more persistent or toxic, such as TCP formed from chlorpyrifos degradation.

Key Roles of Bacteria

Hydrocarbon-degrading bacteria (*Pseudomonas*, *Bacillus*, *Alcanivorax*): Break down petroleum-based pollutants.

Nitrifying and denitrifying bacteria (*Nitrosomonas*, *Nitrobacter*, *Paracoccus*): Convert harmful nitrogen compounds into harmless nitrogen gas.

Sulfate-reducing bacteria (*Desulfovibrio*): Immobilize heavy metals by forming sulfides.

Iron-reducing bacteria (*Geobacter*, *Shewanella*): Reduce metal toxicity and mobility.

Heavy metal-resistant bacteria: Detoxify metals through biosorption and precipitation.

Plant growth-promoting bacteria (PGPB) (*Rhizobium*, *Azospirillum*): Enhance plant growth and support phytoremediation.

Fungi for Bioremediation

Fungi are widely present in agricultural soils and play an important role in degrading pesticides and other pollutants. Their ability to produce diverse enzymes and tolerate high concentrations of contaminants makes them more efficient than many bacteria in certain conditions. Fungi such as *Phanerochaete chrysosporium* are capable of breaking down complex compounds like lignin and polycyclic aromatic hydrocarbons (PAHs). Different

groups of fungi contribute to soil remediation in specific ways. White rot fungi degrade complex organic pollutants through ligninolytic enzymes, while brown rot fungi mainly decompose plant materials like cellulose. Mycoremediation fungi, such as *Pleurotus ostreatus*, help in removing hydrocarbons and heavy metals. Arbuscular mycorrhizal fungi improve plant growth and enhance phytoremediation efficiency. Endophytic fungi increase plant tolerance to stress, whereas chelating and bioaccumulating fungi immobilize or absorb heavy metals, reducing their toxicity.

Actinomycetes for Bioremediation: Actinomycetes are Gram-positive microorganisms known for producing enzymes and bioactive compounds that aid in the degradation of pollutants. They play a significant role in breaking down organic contaminants and improving soil quality. Important genera include *Streptomyces*, which produces enzymes to degrade complex compounds; *Nocardia* and *Gordonia*, which are involved in hydrocarbon degradation; and *Mycobacterium*, which can break down PAHs and other pollutants. Other genera such as *Actinomadura*, *Micromonospora*, and *Actinoplanes* contribute through enzyme production, while *Frankia* improves soil fertility through nitrogen fixation.

Algae for Bioremediation: Algae are effective in bioremediation, especially for removing heavy metals and excess nutrients from contaminated soils. They can absorb and accumulate toxic elements such as cadmium, lead, and arsenic, thereby reducing their

environmental impact. Microalgae like *Chlorella* and *Spirulina* are widely used for heavy metal removal and degradation of organic pollutants. Diatoms help in removing both organic and inorganic contaminants, while green algae and cyanobacteria contribute to nutrient uptake and nitrogen fixation. Other organisms like *Euglena* and macroalgae also assist in pollutant removal. In many cases, mixed algal cultures are used to target a wide range of contaminants effectively.

Recent Advancements in Bioremediation

Bioremediation is a rapidly evolving field, with recent developments focusing on advanced molecular and biotechnological approaches. Techniques such as gene editing and recombinant DNA technology are being used to develop microorganisms with enhanced pollutant-degrading abilities. Tools like CRISPR-Cas, TALENs, and ZFNs have opened new possibilities for improving the efficiency of biodegradation. Another important advancement is the use of microbial glycoconjugates, which increase the availability of pollutants for microbial action. Research is also increasingly focused on microbial consortia, where multiple microorganisms work together, often showing better degradation efficiency than single strains. Studies have demonstrated that mixed cultures can achieve significantly higher removal of pesticides, highlighting their potential in large-scale applications.

Conclusion

Environmental pollution remains a major global concern, particularly due to pesticide accumu-

Table 1: Examples of Different Microorganism used in Bioremediation

Target	Pesticide	Microorganism	References
Insects	Chlorpyrifos	<i>Ochrobactrum</i> sp. JAS2	Abraham <i>et al.</i> , 2016
	Cypermethrin	<i>Bacillus subtilis</i>	Gangola <i>et al.</i> , 2018
	DDT	<i>Fomitopsis pinicola</i> and <i>Ralstonia pickettii</i>	Purnomo <i>et al.</i> , 2020
	Deltamethrin	<i>Streptomyces rimosus</i>	Khajezadeh <i>et al.</i> , 2020
	Fentopropathrin	<i>Rhodopseudomonas palustris</i> PSB-S	Luo <i>et al.</i> , 2018
	Phorate	<i>Brevibacterium frigoritolerans</i> , <i>Bacillus aerophilus</i> and <i>Pseudomonas fulva</i>	Jariyal <i>et al.</i> , 2018
Herbs	Acetochlor	<i>Tolypocladium geodes</i> and <i>Cordyceps</i>	Erguven <i>et al.</i> , 2018
	Glyphosate	<i>Fusarium</i>	Castro <i>et al.</i> , 2007
	Glyphosate and its metabolites	<i>Pseudomonas fluorescens</i>	Kaczynski <i>et al.</i> , 2020
	Penoxsulam	<i>Aspargillus flavus</i> and <i>Aspargillus niger</i>	Sondhia <i>et al.</i> , 2016
Fungi	Epoxiconazole and fludioxonil	<i>Pseudomonas</i> , <i>Rhodobacter</i> , <i>Ochrobactrum</i> , <i>Comamonas</i> , <i>Hydrogenophaga</i> , <i>Azospirillum</i> , <i>Methylobacillus</i> and <i>Acinetobacter</i>	Alexandrino <i>et al.</i> , 2020
	Tebuconazole	<i>Serratia marcescens</i>	Wang <i>et al.</i> , 2018

lation in soils. Microbial bioremediation offers an effective and eco-friendly solution to reduce these risks while maintaining agricultural productivity. Continued research is essential to discover new microorganisms with strong detoxification abilities and to improve existing technologies for better field-level application.

References

- Abraham, J. and Silambarasan, S. (2016). Biodegradation of chlorpyrifos and its hydrolysis product 3,5,6-trichloro-2-pyridinol using a novel bacterium *Ochrobactrum* sp. JAS2: A proposal of its metabolic pathway. *Pesticide Biochemistry and Physiology*, 126: 13-21.
- Alexandrino, D. A. M., Mucha, A. P., Almeida, C. M. R. and Carvalho, M. F. (2020). Microbial degradation of two highly persistent fluorinated epoxiconazole and fludioxonil. *Journal of Hazardous Material*, 394: 122545.
- Barbato, R. A. and Reynolds, C. M. (2021). Bioremediation of contaminated soils. In *Principles and Applications of Soil Microbiology*. Elsevier, pp 607-631.
- Bhatt, P., Bhatt, K., Sharma, A., Zhang, W., Mishra, S. and Chen, S. (2021). Biotechnological basis of microbial consortia for the removal of pesticides from the environment. *Critical Reviews in Biotechnology*, 41: 317-338.
- Castro, J.V., Peralba M. C. R. and Ayub, M. A. Z. (2007). Biodegradation of the herbicide glyphosate by filamentous fungi in platform shaker and batch bioreactor. *Journal of Environmental Science and Health Part B.*, 42: 883-886.
- Das, S. and Dash, H. R. (2014). Microbial Bioremediation: A potential tool for restoration of contaminated areas. In: *Microbial biodegradation and bioremediation* Elsevier. pp: 1-21.
- Erguven, G. O. (2018). Comparison of some soil fungi in bioremediation of herbicide acetochlor under agitated culture media. *Bulletin of Environment Contamination and Toxicology*, 100: 570-575.

- Gangola, S., Sharma, A., Bhatt, P., Khati, P. and Chaudhary, P. (2018). Presence of esterase and laccase in *Bacillus subtilis* facilitates biodegradation and detoxification of cypermethrin. *Scientific Reports*, 8: 12755.
- Jariyal, M., Jindal, V., Mandal, K., Gupta, V. K. and Singh, B. (2018). Bioremediation of organophosphorus pesticide phorate in soil by microbial consortia. *Ecotoxicology and Environmental Safety*, 159: 310-316.
- Kaczynski, P., Lozowicka, B., Wolejko, E., Iwaniuk, P., Konecki, R., Dragowski, W., Lozowicki, J., Amanbek, N., Rusilowska, J. and Pietraszko, A. (2020). Complex study of glyphosate and metabolites influence on enzymatic activity and microorganisms association in soil enriched with *Pseudomonas fluorescens* and sewage sludge. *Journal of Hazardous Materials*, 393: 122-443.
- Kandasamy, S., Narayanan, M., He, Z., Liu, G., Ramakrishnan, M., Thangavel, P., Pugazhendhi, A., Raja, R. and Carvalho, I. S. (2021). Current strategies and prospects in algae for remediation and biofuels: An overview. *Biocatalysis and Agricultural Biotechnology*.
- Wang, X., Hou, X., Liang, S., Lu, Z., Hou, Z., Zhao, X., Sun, F. and Zhang, H. (2018). Biodegradation of fungicide Tebuconazole by *Serratia marcescens* strain B1 and its application in bioremediation of contaminated soil. *International Journal of Biodeterior. Biodegradation*, 127: 185-191.
- Randika, J. L. P. C., Bandara, P. K. G. S. S., Soysa, H. S. M., Ruwandeepika, H. A. D. and Gunatilake, S. K. (2022). Bioremediation of pesticide-contaminated Soil: A Review on Indispensable Role of Soil Bacteria. *Journal of Agricultural Science*, 17(1).
- Khajezadeh M., Abbaszadeh-Goudarzi K., Pourghadamyari H. and Kafilzadeh F. (2020). A newly isolated *Streptomyces rimosus* strain capable of degrading deltamethrin as a pesticide in agricultural soil. *Journal of Basic Microbiology*, 60: 435-443.
- Luo, X., Zhang, D., Zhou, X., Du J., Zhang, S. and Liu, Y. (2018). Cloning and characterization of a pyrethroid pesticide decomposing esterase gene, *Est3385*, from *Rhodospseudomonas palustris* PSB-S. *Scientific Reports*, 8: 7384.
- Pimmata, P., Reungsang, A. and Plangklang, P. (2013). Comparative bioremediation of carbofuran contaminated soil by natural attenuation, bioaugmentation and biostimulation. *Int. Biodeter. Biodegr.*, 85: 196-204.
- Purnomo, A. S., Sariwati, A. and Kamei, I. (2020). Synergistic interaction of a consortium of the brown-rot fungus *Fomitopsis pinicola* and the bacterium *Ralstonia pickettii* for DDT biodegradation. *Heliyon*.
- Verma, A. (2021). Bioremediation techniques for soil pollution: An introduction. *Biodegradation technology of organic and inorganic pollutants*.

- Sondhia, S., Rajput, S., Varma, R. K. and Kumar, A. (2016). Biodegradation of the herbicide penoxsulam (triazolopyrimidine sulphonamide) by fungal strains of *Aspergillus* in soil. *Applied Soil Ecology*, 105: 196-206.
- Tiwari, D., Bhati, P., Das, P. and Shouch, S., 2018. Potential of actinomycetes as bioremediating and biocontrolling agents. *International Journal of Biomedical Engineering*, 3(2): 25-37.
- Vaksmaa, A., Guerrero-Cruz, S., Ghosh, P., Zeghal, E., Hernando-Morales, V. and Niemann, H. (2023). Role of fungi in bioremediation of emerging pollutants. *Frontiers in Marine Science*, 10.
- Xu, R., Zhang, M., Lin, H., Gao, P., Yang, Z., Wang, D., Sun, X., Li, B., Wang, Q. and Sun, W. (2022). Response of soil protozoa to acid mine drainage in a contaminated terrace. *Journal of Hazardous Materials*, 421.

Beejamrit or (Beejamrutha): A Low-cost, Natural Solution for Healthier Seed Germination

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Introduction

Beejamrit is an ancient organic formulation used as a seed treatment in organic and natural farming in India, sources of enriched microbial niche, including several plant growth- promoting bacteria capable of synthesizing plant growth regulators the microbiological properties of beejamrit and their temporal changes after different incubation periods, application in seed treatment and including the plant beneficial bacteria such as the free-living nitrogen fixers (FNFs) and phosphate solubilizers (PSBs) proliferates progressively up to 4 and 5 days of incubation and reports the total indolic content of beejamrit including indole 3-acetic acid (IAA) beejamrit as a potential seed priming agent in agriculture (Mukherjee *et al.*, 2022). Beejamrit influence of organic manures applications with beejamrit inoculation on economics of summer moong bean. The experiment included combination of organic manures and inoculations. Result highest gross return achieved that the integrated application of 50% FYM+50%RND through vermicompost+ seed inoculation with beejamrith inoculation during both the years. This integrated application led to maximum net return in 2022, while highest in 2023 obtain (100% RND through vermicompost without inoculation). Application of 100% RND through

FYM + beejamrit inoculation result in highest cost of cultivation during both years (Parashar *et al.*, 2025) Beejamrit is a key input in natural farming, especially in the Zero Budget Natural Farming (ZBNF) in India, traditional bio-inoculant prepared using indigenous cow-dung, cow-urine, lime, soil, and water used to seed treatment, seed protection or planting material treatment before sowing. Protect from seed-borne and soil-borne diseases, improve germination and promote early seedling vigor, rich in beneficial microorganism colonize the seed surface and surrounding soil, enhance microbial activity, beejamrit help reduce high costs, preserve soil health and support eco-friendly agricultural practices (Palekar *et al.*, 2015).

Benefits of beejamrit

Beejamrit Improves seed germination and seedling health, contains beneficial plant-associated microbes that improve seed germination and seedling survival rates, including production of growth promoters such as indole-3-Acetic Acide (Ahemad *et al.*, 2011). Beejamrit acts as a protective layer like protects against seed-and soil- borne diseases and reducing the attack of harmful pathogens and fungal spores on seeds and young roots (NITI Aayog Natural Farming Guide). Beejamrit enriches soil health with beneficial micro-

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bial activity instead of harming soil fertility as chemical do, leading to healthier soil ecosystem and long-term productivity (Krishi jagran article on beejamrit benefits). Beejamrit seed treatment showed higher seedling growth traits at 180 days example, seedling shoot length 36.90 cm, tap root length 37.57 cm, survival percent 91.50% (Dhatterwal *et al.*, 2024). Beejamrit Seed quality improvement under salinity stress and Beejamrit treatment results in approximately 92% seed germination under non- stress conditions. Under salinity stress, beejamrit significantly improved, shoot length, root length, seedling vigor index. Enhancement in seed quality parameters was attributed to the combined effect of beneficial microorganism and nutrient present in beejamrit (Kiran *et al.*, 2021).



Beejamrit preparation (Natural farming protocol)

Ingredient (for 20 l beejamrit -treats 100 kg seeds)

- ✓ Cow-dung (desi)-5 kg
- ✓ Cow-urine (desi)-5 litres
- ✓ Lime -50 grams
- ✓ Virgin soil-1 kg
- ✓ Water- 20 liters



How to apply beejamrit for seeds

- ✓ Sprinkler or coat beejamrit over seeds, and mix by hand until seeds are uniformly coated.
- ✓ Shade-dry the seed before sowing.
- ✓ For seed with thin seed coat like legumes, a quick dip in beejamrit and shade drying is recommended.
- ✓ 20 l beejamrit is sufficient for 100 kg seeds.

Conclusion

Beejamrit is a cost effective, eco-friendly, and sustainable solution for enhancing seed germination, improving soil fertility, and promoting healthy crop growth, its natural ingredients provides essential nutrients and beneficial microbes that protects seeds from diseases and pathogens and support vigorous plant development by using beejamrit, farmers can reduce dependency on chemical fertilizers and pesticides, and get healthier crops,

higher yields, and more sustainable agriculture system, beejamrit is an important tool in organic farming that's contributes to both economic and environment well-being.

References

- Kiran, S. C. H., Kumar, A. C., Shukla, K. P., Thammineni, K. S. and Reddy, R. P. V. (2021). Beejamrit on seed quality parameters of quinoa and salinity condition. *International Journal of Plant & Soil Science*, 33 (18): 52-58.
- Mukherjee, S., Sain, S., Nasim, M. D., Goswami, R. and Chakraborty, A. (2022). Beejamrit an ancient Indian traditional knowledge of dynamic plant beneficial microbes. *World Journal of Microbiology and Biotechnology*, 38(7):111-116.
- Dhatterwal, G., Dalal, R. P. S., Dalal, M., Kumar, P., Singla, A. and Richa (2024). Effective of beejamrit in seed priming. *International Journal of Plant and Soil Science*, 36(9): 491-501.
- Rahul, H. K., Vasudev, L., Ramakrishna, H., Suresh, D. E. and Chandrvamshi, P. (2025). Benefits of beejamrit and enhancing germination. *International Journal of Research in Agronomy*, 8(1): 95-99.

Physically Effective Fibre in Ruminant Nutrition: A Key Component of Modern Animal Feeding Systems

Ankita Patel, Vaibhav Patel, Gourav Biswas and Goutam Mondal

Abstract

Physically effective fibre (peNDF) has emerged as a crucial concept in ruminant nutrition, bridging the gap between chemical composition and functional effectiveness of fibre. Unlike traditional fibre measures such as Neutral Detergent Fibre (NDF) and Acid Detergent Fibre (ADF), peNDF emphasizes the importance of particle size in stimulating chewing activity and maintaining rumen health. Adequate levels of physically effective fibre enhance saliva production, stabilize rumen pH, improve feed intake, and support milk fat synthesis. This article highlights the role of peNDF in modern animal nutrition, its measurement, and its impact on animal performance, while also discussing practical recommendations and future research needs.

Introduction

Fibre plays a fundamental role in the nutrition of ruminants such as cows, buffaloes, and goats, as it is essential for maintaining rumen health, digestion, and overall productivity. Traditionally, fibre evaluation has relied on parameters like Neutral Detergent Fibre (NDF) and Acid Detergent Fibre (ADF), which mainly describe the chemical composition of feed. However, these measures alone are not sufficient to explain the functional role of fibre within the rumen. To overcome this limitation, the concept of physically effective fibre (peNDF) has been introduced. This concept refers to the portion of fibre that effectively stimulates chewing and rumi-

ation, which is largely influenced by the particle size of the feed. Physically effective fibre integrates both the physical and functional aspects of fibre, making it a more practical indicator of fibre quality. It enhances chewing activity, increases saliva secretion, stabilizes rumen pH, and promotes efficient digestion. These effects ultimately contribute to improved milk fat content and overall animal performance, making peNDF a cornerstone of modern ruminant nutrition.

Forage Particle Size and Measurement of Physically Effective Fibre

Forage Particle Size: The size of forage particles is a critical factor influencing rumen function and

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digestion in ruminants. Very fine particles tend to pass rapidly through the rumen, which reduces chewing activity and limits saliva production. This condition can lead to a decline in rumen pH and negatively affect fibre digestion. In contrast, moderately sized particles provide an optimal balance between rumen retention time and microbial accessibility. They increase the surface area available for microbial action while still promoting sufficient chewing and rumination. Therefore, maintaining an appropriate particle size is essential for maximizing nutrient utilization, improving digestion, and ensuring animal health. However, determining the ideal particle size under practical feeding conditions remains a challenge due to variations in feed types and management systems.

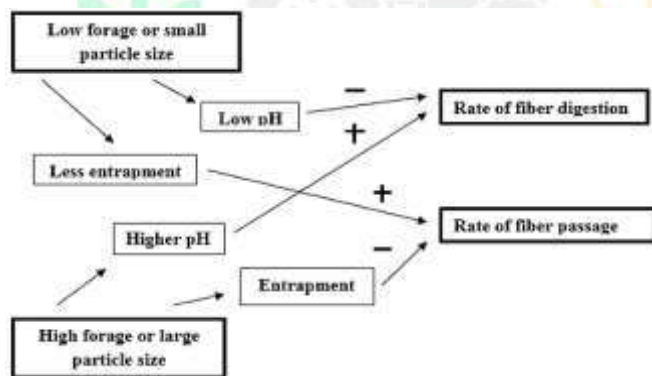


Fig 1: Potential interactions among forage level and particle size on rate of ruminal fibre passage and digestion (Grant *et al.*, 1997)

Measurement of Physically Effective Fibre:

Physically effective fibre is commonly measured using the Penn State Particle Separator (PSPS), a widely used tool that separates feed into different particle size fractions. The value of peNDF is calculated by multiplying the Neutral Detergent Fibre (NDF) content of the feed with a physical

effectiveness factor (pef), which ranges from 0 to 1 and indicates the ability of fibre to stimulate chewing activity. Measurement approaches generally involve estimating peNDF based on particle size distribution or determining NDF content within different particle fractions. Although these methods are practical and widely adopted, they have certain limitations, as they do not fully consider the fermentability of fibre and lack universally standardized recommendations. Despite these limitations, PSPS remains a valuable tool for evaluating the physical effectiveness of fibre in ruminant diets.

Influence of Physically Effective Fibre on Performance of Ruminants

Effect on Chewing Activity: Chewing activity is a fundamental process in ruminants, as it directly influences saliva production, which acts as a natural buffer in the rumen. Diets containing long and coarse fibre significantly increase chewing time, whereas finely ground feeds can reduce chewing activity by 20 to 60 percent. Increased chewing activity enhances rumen stability, promotes microbial growth, and improves overall digestion efficiency. Therefore, physically effective fibre plays a direct role in maintaining proper rumination behavior and digestive health.

Effect on Ruminal pH: Rumen pH is a critical factor for maintaining optimal microbial activity and digestive efficiency, typically ranging between 5.8 and 6.4. Diets high in fermentable carbohydrates can lower rumen pH, increasing the risk of acidosis and other metabolic disorders. In contrast, adequate lev-

els of physically effective fibre stimulate chewing and saliva production, which help buffer rumen acids and maintain a stable pH environment. Thus, a balanced diet containing sufficient peNDF is essential for preserving rumen health and preventing digestive disturbances.

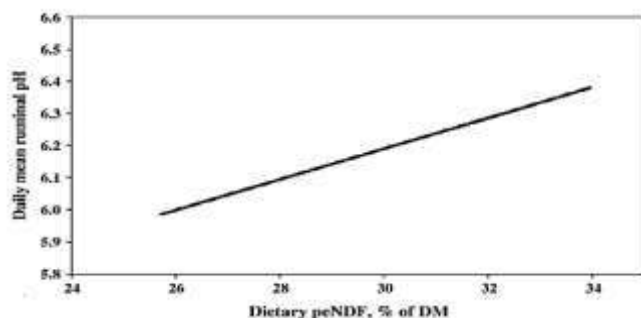


Fig. 2: Effects of dietary peNDF on daily mean ruminal pH in high-producing dairy cows (Zebeli *et al.*, 2021)

Effect on Feed Intake: Feed intake in ruminants is influenced by both the quantity and physical characteristics of fibre. Moderate levels of physically effective fibre improve dry matter intake by enhancing rumen function and digestion. However, excessive fibre can limit intake due to its bulkiness, while insufficient fibre may lead to digestive problems and reduced efficiency. Achieving an optimal balance of peNDF is therefore essential for maximizing feed intake, improving nutrient utilization, and enhancing animal productivity.

Effect on Milk Fat Production: Milk fat synthesis is closely linked to rumen fermentation processes. Higher levels of physically effective fibre promote the production of acetate in the rumen, which is a key precursor for milk fat synthesis. Conversely, low levels of peNDF can disrupt fermentation patterns and result in milk fat depression. Studies indicate that

maintaining approximately 20 to 22 percent peNDF in the diet supports optimal milk fat levels, typically around 3.4 percent, in dairy animals. This highlights the importance of physically effective fibre in improving milk quality as well as quantity.

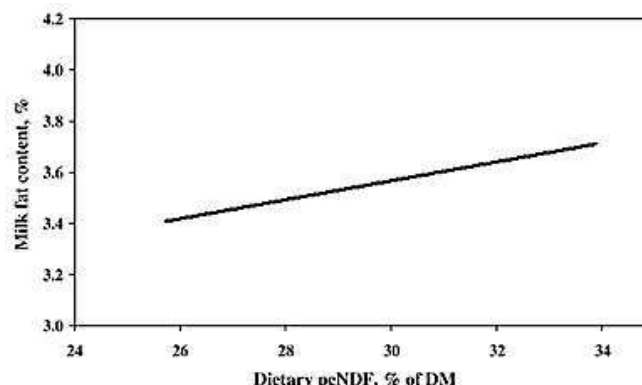


Fig 3: Effects of dietary peNDF on daily milk fat content in high producing dairy cows (Zebeli *et al.*, 2020)

Particle Size and Effective Fibre Recommendations

Nutritional guidelines suggest that total Neutral Detergent Fibre should constitute about 25 percent of the dietary dry matter, with at least 75 percent derived from forage sources. Additionally, physically effective fibre should ideally account for 20 to 22 percent of the total diet. These recommendations provide a general framework for ration formulation; however, precise standards are still evolving due to variations in feed characteristics, animal requirements, and limitations in measurement techniques. Continuous research is needed to refine these guidelines for practical applications.

Practical Applications and Challenges

In modern livestock production systems, maintaining appropriate levels of physically effective fibre is essential for optimizing animal health and

productivity. Tools such as the Penn State Particle Separator are widely used to evaluate feed particle size and ensure balanced ration formulation. Proper management of particle size helps prevent issues such as low rumen pH, inefficient digestion, and reduced milk fat content. However, challenges remain, including variability in feed quality, difficulties in standardizing measurement techniques and the need for greater awareness among farmers regarding the importance of peNDF. Addressing these challenges is crucial for improving the effectiveness of feeding strategies in practical conditions.

Future Perspectives

The future of ruminant nutrition lies in a better understanding of the relationship between fibre characteristics and rumen function. Further research is required to standardize peNDF recommendations, improve measurement techniques, and explore the interactions between fibre, microbial activity and overall animal performance. Advancements in nutritional science will help develop more precise and efficient feeding strategies, contributing to sustainable livestock production.

Conclusion

Physically effective fibre is a vital component of ruminant nutrition, influencing chewing activity, rumen health, feed intake, and milk production. Its effectiveness depends not only on the quantity of fibre but also on its physical characteristics, particularly particle size. Proper management of peNDF ensures stable rumen conditions, efficient

digestion, and improved animal performance. By focusing on the quality and physical effectiveness of fibre, livestock producers can enhance productivity, improve milk quality, and maintain animal health. In modern animal nutrition, physically effective fibre serves as a key factor in achieving efficient and sustainable livestock production.

References

- Zebeli, Q., Tafaj, M., Steingass, H., Metzler, B. and Drochner, W. (2016). Effects of physically effective fiber on digestive processes and milk fat content in early lactating dairy cows fed total mixed rations. *Journal of Dairy Science*, 89(2): 651-668.
- Zebelia, Q., D. Mansmanna, H. Steingassa and B. N. Ametaj. (2010). Balancing diets for physically effective fibre and ruminally degradable starch: A key to lower the risk of sub-acute rumen acidosis and improve productivity of dairy cattle. *Livestock Science*, 127: 1-10.
- Kononoff, P. J., Heinrichs, A. J. and Lehman, H. A. (2023). The effect of corn silage particle size on eating behaviour, chewing activities, and rumen fermentation in lactating dairy cows. *Journal of Dairy Science*, 86: 3343-3353.
- Van Soest, P. J. (1965). Symposium on Factors Influencing the Voluntary Intake of Herbage by Ruminants: Voluntary Intake in Relation to Chemical Composition and Digestibility. *Journal Animal Science*, 24(3): 834-843.
- Yang, W. Z. and Beauchemin, K. A. (2016). Physic-

ally effective fiber: method of determination and effects on chewing, ruminal acidosis, and digestion by dairy cows. *Journal of Dairy Science*, 89: 2618-2633.

Zhao, X. H., Zhang, T., Xu, M. and Yao, J. H. (2023). Effects of physically effective fiber on chewing activity, ruminal fermentation and digestibility in goats. *Journal Animal Science*, 89: 501-509.



Climate Smart Agriculture: A Comprehensive Approach to Sustainable and Resilient Agriculture

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Introduction

Agriculture is one of the most climate-sensitive sectors, directly influenced by variations in temperature, rainfall, and extreme weather events. In recent decades, the increasing intensity of climate change has posed serious challenges to agricultural sustainability, food security, and rural livelihoods across the globe. Rising temperatures, erratic precipitation patterns, prolonged droughts, floods, and the emergence of new pests and diseases have significantly affected crop productivity and farm income. These changes have disrupted traditional farming practices and increased uncertainty in agricultural production systems. In this context, Climate Smart Agriculture (CSA) has emerged as a strategic and holistic approach to address these challenges. It seeks to transform agricultural systems in a manner that ensures food security while adapting to climate change and mitigating its adverse effects.

Concept and Definition of Climate Smart Agriculture

Climate Smart Agriculture is an integrated approach that combines agricultural development with climate resilience. It is defined by the Food and Agriculture Organization (FAO) as an approach that

helps guide actions needed to transform and reorient agricultural systems to effectively support development and ensure food security in a changing climate.

The concept of CSA is built upon three interrelated objectives, namely increasing agricultural productivity and incomes in a sustainable manner, enhancing resilience and adaptive capacity to climate change, and reducing or removing greenhouse gas emissions wherever possible. These objectives are interconnected and must be addressed simultaneously to ensure long-term sustainability. CSA thus provides a balanced framework that aligns agricultural development goals with environmental conservation and climate adaptation strategies.

Need for Climate Smart Agriculture

The need for Climate Smart Agriculture has become increasingly important due to the growing vulnerability of agriculture to climate-related risks. Climate change has altered rainfall patterns, increased temperature variability, and intensified the frequency of extreme weather events such as droughts and floods. These changes have adversely affected crop yields and livestock productivity, thereby threatening food security. At the same time, the global population is increasing, leading to higher

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demand for food, which places additional pressure on natural resources.

Soil degradation, water scarcity, and loss of biodiversity further complicate the situation. Small and marginal farmers are particularly vulnerable due to their limited access to resources, technology, and information. In this context, CSA offers a sustainable pathway to address these challenges by enhancing productivity, improving resilience, and conserving natural resources.

Principles of Climate Smart Agriculture

CSA is not a single technology but a holistic approach guided by the following principles:

Sustainability: Efficient use of natural resources without degrading them

Resilience: Ability to withstand and recover from climate shocks

Productivity: Enhancing yields and farm income

Mitigation: Reducing emissions and carbon footprint

Location-specificity: Practices tailored to local agro-climatic conditions

Integration: Combining crops, livestock, forestry, and fisheries

Practices and Technologies in Climate Smart Agriculture

Climate Smart Agriculture encompasses a wide range of practices and technologies aimed at enhancing productivity and resilience while reducing environmental impact. Crop management practices such as the use of drought-tolerant and flood-resistant crop varieties help farmers adapt to chang-

ing climatic conditions. Adjusting sowing dates and adopting crop diversification strategies also contribute to reducing risks associated with climate variability. Soil management practices, including conservation agriculture, minimum tillage, and organic farming, improve soil health and enhance carbon sequestration. Efficient water management techniques such as drip irrigation, sprinkler systems, and rainwater harvesting help conserve water and improve irrigation efficiency.

Agroforestry, which involves integrating trees with crops and livestock, provides multiple benefits including carbon sequestration, improved biodiversity, and additional income sources. Livestock management practices such as improved feeding and manure management also contribute to reducing greenhouse gas emissions.

Climate Smart Agriculture in the Indian Context

India is particularly vulnerable to climate change due to its dependence on monsoon-based agriculture and the predominance of smallholder farmers. Recognizing this vulnerability, the Government of India has launched several initiatives to promote Climate Smart Agriculture. The National Mission for Sustainable Agriculture focuses on enhancing agricultural productivity while ensuring environmental sustainability. Programs such as the Pradhan Mantri Krishi Sinchayee Yojana aim to improve water use efficiency, while the Soil Health Card Scheme promotes balanced nutrient management. The Paramparagat Krishi Vikas Yojana encourages organic farming practices.

Research institutions such as the Indian Council of Agricultural Research and State Agricultural Universities play a crucial role in developing climate-resilient technologies. Additionally, Krishi Vigyan Kendras serve as important platforms for transferring CSA practices to farmers through training and demonstrations.

Role of Agricultural Extension in Climate Smart Agriculture

- ✓ Technology transfer between research institutions and farmers
- ✓ Capacity building through training and demonstrations
- ✓ Promotion of participatory and farmer-centric approaches
- ✓ Dissemination of climate information and ICT-based advisories
- ✓ Facilitation of adoption of climate-resilient practices

Benefits of Climate Smart Agriculture

The adoption of Climate Smart Agriculture offers multiple benefits across economic, environmental and social dimensions. Economically, it enhances productivity and income stability by reducing the risks associated with climate variability. Environmentally, it contributes to soil conservation, water management, and reduction of greenhouse gas emissions, thereby promoting ecological sustainability. Socially, it improves food security, enhances resilience of farming communities, and supports sustainable livelihoods. By integrating adaptation and mitigation strategies, CSA provides a compreh-

ensive approach to sustainable agricultural development.

Challenges in Implementing Climate Smart Agriculture

- ✓ Lack of awareness and knowledge among farmers acts as a major barrier to the adoption of CSA practices.
- ✓ High initial investment costs associated with technologies such as drip irrigation, protected cultivation and improved inputs limit accessibility, especially for small and marginal farmers.
- ✓ Limited access to credit and financial services constrains farmers from investing in climate-resilient technologies and practices.
- ✓ Inadequate extension support reduces the effective dissemination of CSA knowledge, technologies, and advisory services.
- ✓ Weak institutional capacity further hampers large-scale implementation and coordination of CSA initiatives.

Future Prospects of Climate Smart Agriculture

The future of Climate Smart Agriculture lies in the integration of advanced technologies and innovative approaches. The use of artificial intelligence, remote sensing, and data analytics can improve climate prediction and decision-making processes. Strengthening climate information services and improving access to real-time data will enable farmers to make informed decisions.

Policy support and increased investment in sustainable agriculture are essential for scaling up CSA practices. Public-private partnerships can also

play a significant role in promoting innovation and improving access to resources. Enhancing the capacity of extension systems and empowering farmers through education and training will be crucial for the successful implementation of CSA.

Conclusion

Climate Smart Agriculture represents a transformative approach to addressing the challenges posed by climate change while ensuring food security and sustainable development. By integrating productivity, resilience, and mitigation, CSA provides a comprehensive framework for sustainable agricultural practices. Its successful implementation depends on strong institutional support, effective policies, technological innovations, and active participation of farmers. As climate change continues to impact agriculture, the adoption of Climate Smart Agriculture will be essential for building resilient agricultural systems and securing the livelihoods of millions of farmers worldwide.

Agro-Processing Units Managed by Rural Women: Opportunities and Challenges

Dipali Dubey, Sudhir Kumar Mishra and Ashritmani Bhaskar

Abstract

Agro-processing is a commercial operation that initiate from the farm and concludes at the fork of a consumer. Its main areas of interest are value addition, post -harvest management, and the use of agriculture commodities' byproducts. The agro-processing industry's explosive rise in recent decades has greatly aided rural development by creating job options, especially for rural women who frequently continue to work in informal and covert jobs. The current study looks at how women manage agro-processing facilities and assesses the advantages and disadvantages of their involvement in this industry. These results show that women -owned agro-processing businesses help increase revenue, use waste, and lower post-harvest losses. However, obstacles including poor infrastructure, weak market connections restricted financial availability, and insufficient technical expertise prevent them from reaching their full potential. Women -managed agro-processing businesses in rural regions can grow more sustainably if institutional support, skill development, and market access are strengthened.

Introduction

The agro-processing sector play a pivotal role in raising rural income and promoting economic growth. Agro-processing centre is a business that processes agricultural products after harvest to make them more marketable and storable. It primarily addresses value addition, by-product usage, and post-harvest protection for all agricultural commodities. Over the past fifty years, this industry has experienced tremendous growth. Due to its patriarchal culture, India often assigns women to do household chores while males handle outside work.

Because it can be done at home with fewer resources, agro-processing has so gained a lot of popularity among the women. Small scale agro-processing facilities can empower rural women and increase their capacity, dispelling the myth that they are helpless and cannot make any real contributions to economic growth. The SMCS is undoubtedly serving as a beacon of hope for the wellbeing of the nation' women, the vast majority of whom lead dismal lives filled with discrimination, humiliation, and hardship. With consistently rising sales, profitability and business turnover, the fruit processing cooperative

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was seen to be on a path of steady expansion. The indicators of success were the sound and healthy financial ratios, which can be further enhanced by extending market opportunities, diversifying the range of processed goods, developing competent management and sound financial practices, and boosting processing capacity. One of the main players in the horticulture industry, women farmers are heavily involved in both on and off-farm operations. They have played a crucial role in the expansion of this industry, making significantly more contributions than their counterparts by carrying out labors-intensive, time-consuming, and repetitive tasks that are frequently labeled as “unskilled activities” There is a noticeable gender disparity because the extent of their involvement is rarely visible. Since they make up the sector’s vast support network, it is important to maximize their potential by recognizing their strength, addressing their shortcomings, giving them plenty of opportunities, and reducing their risks. With the advancement of time agro-processing education for women is crucial for boosting rural livelihoods and agricultural economy. As time goes on, a lot of new technologies are being created with women’s ergonomics and working situations in mind. These technologies are intended to improve agricultural product processing efficiency and lessen physical strain. Because they have greater access to information and education, people who live in cities are somewhat aware of these developments. But many women in rural regions are still ignorant of

these opportunities. Although many women work in agriculture in rural areas, few of them participate in organized agro-processing industries. This is mostly due to the fact that training programs and contemporary processing technologies frequently fail to adequately reach them.

It's interesting to note that while less educated women frequently engage in more practical agricultural labor, more educated women are occasionally less involved in small-scale agricultural processing operations. These women can make a substantial contribution to local agro-processing operations if they are given the right training, awareness campaigns, and chances for skill development. Agro-processing can be significantly improved by giving less educated rural women access to technology and training. Higher educated women can also have a significant impact on marketing tactics, value addition, product quality, and the use of contemporary processing technology. When combined, these initiatives can give local agricultural products a robust and sustainable future. Thus, encouraging agro-processing businesses run by rural women can have a big impact on raising their socioeconomic standing and boosting the rural economy. The prospects for rural women to engage in agro-processing activities are highlighted in this article, along with the main obstacles they encounter while starting and running these businesses.

Review of literature

Women are essential to the world economy, especially in underdeveloped countries where they

are frequently the backbone of small-scale processing and agriculture (Agenor and Agenor, 2014, Anik and Rahman, 2021; Organization for Economic Cooperation and Development (OECD), 2011). Globally, structural obstacles to gender equality and discrimination still exist despite changes in society demands and the workplace. Gender differences in labor force participation, pay disparity, occupational segregation, unfavorable working conditions, and the burden of unpaid household and care work, especially in the informal sector, are some of the ways that these issues show up (Zakuan and Hassan, 2016; Commission on the status of women, 2017). In response, women's empowerment has become a key goal in the quest for sustainable development (Ghosh, 2022; Huis *et al.*, 2017). The conversation around women's empowerment has drawn a lot of interest from academics, businesses, and policy-maker, according to Purnamawati and Utama (2019) and the OECD (2011).

Higher educated women should be encouraged to pursue careers in agro-processing; if at all possible, agro-processing should offer incentives to attract more women with lower incomes. In order to fight the poverty plaguing the rural population, all of these will guarantee food security (Adesope *et al.*, 2010). One of the most significant changes for female employment over past two decades may be the widespread integration of women in the packing stage of non-traditional agro-export production (Deere, 2005).

Opportunities and Challenges

Globalization has drawbacks, just like the two sides of a coin. Our small-scale cottage industries have been forced to close due to MNCs' invasion of the local market. Now, global agribusiness is trying to take over food processing by portraying stale food wrapped in plastic and aluminum as modern and fresh, locally produced food as archaic.

Agro-processing facilities run by rural women present a number of chances for social and economic advancement. These units give women a reliable source of income and aid in the creation of jobs locally. Pickles, jams, sauces, flour, and other value-added goods can be made from agricultural products such as fruits, vegetables, grains, and pulses through agro-processing. This value addition lowers post-harvest losses while raising the market value of raw products. Additionally, agro-processing empowers rural women to actively engage in the rural economy and promotes entrepreneurship among them. The creation of such units is further encouraged by government initiatives, training courses, and assistance from self-help groups (SHGs), which enhance rural women's financial independence. The all India coordinated research project on post-harvest Engineering and technology has been working on the creation, oversight and promotion of agro processing facilities (APC) under the auspices of ICAR. In rural catchments, APC establishments by its operating centers has been highly successful in reducing post-harvest losses, adding value, creating jobs, and increasing revenue. The AICRP on PHET centers in

Bangalore, Bhubaneswar, and Coimbatore have effectively built ACPs run exclusively by women.

Challenges

Despite the numerous opportunities, managing agro-processing facilities presents a number of difficulties for rural women. One of the major challenges is the lack of technical knowledge and training related to modern processing techniques and equipment. The creation and growth of such entities are further hampered by restricted access to credit facilities and financial resources. Another major problem is the marketing of processed goods, since rural women frequently struggle to compete with well-known brands and access larger markets. The effectiveness of agro-processing operation is also impacted by inadequate transportation, storage, and processing infrastructure. In addition, domestic duties and societal and cultural hurdles may prevent women from actively engaging in entrepreneurial endeavors.

Conclusion

Agro-processing units managed by rural women represent a promising pathway for achieving sustainable rural development and strengthening women's socio-economic empowerment. Services like training and credits alone are insufficient to increase women's empowerment and appeal to the agro-processing industry. This can be resolved by enhancing rural women's general intelligence to comprehend the provision of credit acquisition and spending it with appropriate planning, training, development of women's business skill, market

research, etc. (to identify domestic demand and export potential for processed product, identify potential threat from imports). Advocacy for policies is necessary to support from women's organizations and cooperatives will be crucial to strengthening this policy, both locally and nationally through trade associations and women's unions.

References

- Adesope, O. M., Nwakwasi, R. N., Mathews-Njoku, E. C. and Chikaire, J. (2010). The extent of rural women's involvement in agro-processing in the National Special Programme for Food Security in Imo State, Nigeria. *Report and Opinion*, 2(6): 69-73.
- Deere, C. D. (2005). The feminization of Agriculture: Economic restructuring in rural Latin America. United Nations Research Institute for Social Development.
- Food and Agriculture Organization. (2003). The extraordinary contribution of women food farmers to Africa. Food Security and Nutrition Analysis Unit (FSNAU).
- Goyal, M. and Prakash, J. (2011). Women entrepreneurship in India: Problems and prospects. *International Journal of Multidisciplinary Research*, 1(5).
- Okoro, C. N. and Amaechi, E. C. C. (2008). Gender issues in agricultural transformation. In Proceedings of the 17th Annual Congress of the Nigerian Rural Sociological Association, National Root Crops Research Institute, Umudike, Abia State, Nigeria.

- Jain, R. and Nehru, P. J. (2017). Government initiatives for women empowerment: A movement towards social change. *South Asian Journal of Participative Development*, 17(1): 14.
- Kumar, K. and Radha, K. (2021). Women entrepreneurs in rural sector: Issues and challenges. *Journal of Critical Reviews*, 7(16).
- Oladejo, J. I., Olawuyi, S. O. and Anjorin, T. D. (2011). Analysis of women participation in agricultural production in Egbedore Local Government Area of Osun State, Nigeria. *International Journal of Agricultural Economics and Rural Development*, 4(1)
- Onwurafor, E. U. and Enwelu, I. A. (2013). Rural women entrepreneurship in agro-processing in Enugu State, Nigeria. Centre for Entrepreneurship & Development Research, University of Nigeria, Nsukka.
- Singh, P., Jhamtani, A., Bhadauria, C., Srivastava, R., Singh, R. and Singh, J. (2004). Participation of women in agriculture. *Indian Journal of Extension Education*, 30(3-4): 23-27

Early Maturing Crop Varieties for Multiple Cropping Systems: A Key to Higher Farmer Income

Ghanprakash Ghoretha, Deepak Gupta and Chelsi

Abstract

Early maturing crop varieties play an important role in increasing cropping intensity and improving farm productivity. These varieties allow farmers to grow multiple crops in a year by utilizing available land, water, and time efficiently. Early maturing pulses also improve soil fertility through biological nitrogen fixation and help reduce production risks under changing climatic conditions. Their adoption can significantly enhance farmers' income and support sustainable agriculture.

Agriculture in India is largely dependent on the efficient use of land, water and other resources. Farmers are constantly trying to increase productivity from limited land holdings. One effective approach to achieve this goal is the adoption of early maturing crop varieties, which allows farmers to grow more than one crop in the same field within a year. Early maturing varieties play a crucial role in promoting multiple cropping systems, improving farm income, and ensuring better use of natural resources.

Concept of Early Maturing Varieties

Early maturing crop varieties are those that complete their life cycle in a shorter duration compared to traditional varieties. For example, while a normal crop variety may take 110-120 days to mature, an early maturing variety may complete its growth within 70-90 days. Because of this shorter duration, farmers can cultivate additional crops in the

same field during the same agricultural year. The development of such varieties is possible due to continuous research in the field of Plant Breeding and Genetics. Scientists select and develop crop varieties that mature earlier without compromising yield or quality. These varieties are also often bred to tolerate stresses such as drought, pests, and diseases.

Importance of Multiple Cropping Systems

Multiple cropping refers to the practice of growing two or more crops on the same land in one year. This system is widely practiced in regions where the climate and irrigation facilities permit several crop seasons. Adoption of early maturing varieties helps farmers practice different types of cropping systems such as:

Double Cropping: Growing two crops in one year on the same field, such as wheat followed by mungbean.

Triple Cropping: Growing three crops in a year,

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such as rice-mustard-green gram.

Relay Cropping: Sowing the next crop before the harvest of the previous crop to save time.

These systems increase land productivity, improve soil fertility, and provide farmers with continuous income throughout the year.

Advantages of Early Maturing Crop Varieties

Early maturing crop varieties are those that complete their life cycle in a shorter period compared to traditional varieties. The adoption of such varieties offers several advantages to farmers, especially in regions where land resources are limited and climatic conditions are unpredictable.

Increased Cropping Intensity: One of the most important benefits of early maturing varieties is that they allow farmers to grow more crops in the same field within a year. Because these varieties mature quickly, the land becomes available earlier for the next crop. This enables farmers to adopt double or triple cropping systems, thereby increasing overall production.

Efficient Use of Land Resources: Early maturing varieties help in better utilization of agricultural land. When a crop is harvested early, farmers can prepare the field in time for the next crop. This prevents land from remaining fallow and improves the overall productivity of the farm.

Reduced Risk from Adverse Weather Conditions: Short-duration crops can escape unfavorable weather conditions such as late-season drought, frost, excessive rainfall, or heat stress. Early harvesting reduces the chances of crop damage and ensures

stable production even in uncertain climatic conditions.

Better Water Management: Early maturing crops generally require less irrigation compared to long-duration varieties. This is particularly beneficial in areas with limited water availability or rainfed farming systems.

Higher Farm Income: Since early maturing varieties allow farmers to cultivate additional crops in a year, the total production from the same piece of land increases. This leads to higher income and better economic stability for farmers.

Timely Availability of Food and Fodder: Early harvesting ensures that food grains and fodder become available sooner. This is important for maintaining household food security as well as livestock nutrition.

Suitable for Climate Change Conditions: With increasing climate variability, early maturing varieties help farmers avoid extreme climatic events such as drought or floods. These varieties therefore contribute to climate-resilient agriculture.

The development of such varieties is made possible through continuous research in Plant Breeding and Genetics, where scientists select and improve crop plants with desirable traits like early maturity, high yield, and stress tolerance.

Role of Early Maturing Pulses in Cropping Systems

Pulse crops play an important role in sustainable agriculture because of their short duration, low input requirement and ability to improve soil fertility

Early maturing pulses are particularly useful in multiple cropping systems.

Inclusion in Crop Rotation: Early maturing pulse crops such as mungbean, urdbean, and cowpea can easily fit into crop rotations. For example, farmers can grow mungbean after the harvest of wheat during the summer season. This practice improves soil fertility and provides an additional source of income.

Improvement of Soil Fertility: Pulse crops have the unique ability to fix atmospheric nitrogen through symbiotic bacteria present in their root nodules. This process enriches soil nitrogen content and reduces the need for chemical fertilizers for the following crops.

Efficient Utilization of Residual Soil Moisture: Early maturing pulses can be grown using the residual moisture left in the soil after the harvest of a major crop. This reduces irrigation requirements and helps utilize natural resources more efficiently.

Breaking Pest and Disease Cycles: Including pulses in cropping systems helps break the life cycle of pests and diseases that commonly affect cereal crops. This reduces the dependence on chemical pesticides and promotes sustainable farming.

Additional Income and Nutritional Security: Pulses are rich in protein and are an essential part of human nutrition. Growing early maturing pulses not only provides farmers with additional income but also contributes to better nutritional security for rural households.

Improving Soil Structure: Pulse crops improve soil structure and aeration through their root system.

After harvest, the remaining plant residues add organic matter to the soil, improving soil health in the long term.

Management Practices for Early Maturing Pulse Crops

To achieve maximum yield and benefit from early maturing pulses, farmers must follow proper crop management practices.

Selection of Suitable Varieties: Farmers should select improved and regionally recommended varieties. Early maturing varieties should have characteristics such as high yield potential, disease resistance, and adaptability to local climatic conditions.

Land Preparation: Proper land preparation is essential for good crop establishment. The field should be ploughed two to three times to obtain a fine tilth. Good soil preparation ensures better seed germination and root development.

Seed Treatment: Seed treatment helps protect the crop from soil-borne diseases and pests during the early stages of growth. Seeds should be treated with recommended fungicides or biofertilizers before sowing.

Optimum Time of Sowing: Timely sowing is very important for early maturing crops. Delayed sowing can reduce yield and affect crop growth. Farmers should follow the recommended sowing window for their region.

Proper Seed Rate and Spacing: Maintaining the correct seed rate and spacing ensures adequate plant population in the field. Proper spacing also allows better sunlight penetration and reduces competition

for nutrients.

Balanced Nutrient Management: Although pulses require less fertilizer compared to cereals, balanced nutrient application is still necessary. Application of phosphorus and other micronutrients helps in better root development and nodulation.

Irrigation Management: Early maturing pulses generally require limited irrigation. However, critical growth stages such as flowering and pod formation require adequate moisture for optimum yield.

Weed Management: Weeds compete with crops for nutrients, water, and sunlight. Early weed control through manual weeding or suitable herbicides helps maintain healthy crop growth.

Pest and Disease Management: Integrated pest management practices should be followed to control insect pests and diseases. Farmers should regularly monitor their fields and apply control measures when necessary.

Timely Harvesting: Early maturing pulses should be harvested as soon as the pods mature. Delayed harvesting can lead to shattering losses and reduction in grain quality.

Challenges in Adoption

Although early maturing varieties offer many advantages, farmers may face certain challenges such as:

- ✓ Limited availability of quality seed
- ✓ Lack of awareness about suitable varieties
- ✓ Improper crop management practices

To overcome these challenges, agricultural extension services, research institutions, and farmer

training programs play an important role in spreading awareness and providing quality seed.

Role of Agricultural Research and Extension

Agricultural scientists are continuously working to develop new crop varieties that mature earlier and perform better under changing climatic conditions. Research institutions also conduct field demonstrations and farmer training programs to promote the adoption of improved varieties. Extension workers and agricultural universities help farmers understand the benefits of early maturing crops and guide them in adopting suitable cropping systems.

Future Prospects

With increasing population and limited agricultural land, it is essential to increase crop productivity through efficient farming practices. Early maturing crop varieties will play a major role in achieving this goal. In the future, advanced breeding techniques and biotechnology will further help in developing varieties that are not only early maturing but also high yielding, stress tolerant, and nutritionally superior.

Conclusion

Early maturing crop varieties provide an excellent opportunity for farmers to increase productivity and profitability through multiple cropping systems. By adopting suitable short-duration crops and proper management practices, farmers can utilize their land more efficiently, reduce production risks, and improve soil health. The adoption of these varieties is a practical and sustain-

able approach to enhancing agricultural production and improving the livelihood of farmers. With continued research, better seed availability, and farmer awareness, early maturing crops will continue to support the growth of modern and profitable agriculture.



Hydroponics and Aeroponics: The Backbone of Vertical Farming

Muneshwar Prasad Mandal and Siddharth Kiran

Introduction

Vertical farming has emerged as a transformative approach to modern agriculture, particularly in urban environments where arable land is scarce. At the core of this innovation lie two advanced soil-less cultivation techniques hydroponics and aeroponics. These systems enable efficient crop production in controlled environments, ensuring higher yields, resource conservation, and year-round farming. As global food demand rises alongside rapid urbanization, hydroponics and aeroponics are increasingly recognized as the technological backbone of vertical farming systems.

Hydroponics: Efficient Nutrient Delivery without Soil

Hydroponics is a method of growing plants in a nutrient-rich water solution, eliminating the need for soil. In this system, plant roots are either submerged in or periodically exposed to a balanced solution containing essential minerals. The controlled delivery of nutrients allows plants to grow faster and more uniformly compared to traditional farming. Additionally, hydroponics uses up to 90% less water than conventional agriculture, as water is recirculated within the system. This method is highly adaptable and widely used in vertical farms for culti-

vating leafy greens, herbs, and even fruits like strawberries. Techniques such as Nutrient Film Technique (NFT), Deep Water Culture (DWC), and drip systems further enhance efficiency. Hydroponics also minimizes the risk of soil-borne diseases and reduces the need for pesticides, making it a cleaner and more sustainable option for urban food production.

Aeroponics: Maximizing Growth through Air and Mist

Aeroponics represents a more advanced evolution of hydroponics, where plant roots are suspended in air and periodically misted with a nutrient solution. This approach ensures maximum oxygen exposure to the roots, which significantly enhances nutrient absorption and accelerates plant growth. The fine mist delivery system uses minimal water often even less than hydroponics making aeroponics one of the most resource-efficient agricultural technologies. Because of its precision and efficiency, aeroponics is often used in high-tech vertical farms and research facilities. It is particularly suitable for crops that require rapid growth cycles and high productivity. However, the system demands careful monitoring and technical expertise, as any interruption in misting can quickly affect plant

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health.

Role in Vertical Farming Systems

Both hydroponics and aeroponics are integral to vertical farming, where crops are grown in stacked layers within controlled indoor environments. These systems work seamlessly with artificial lighting (such as LED grow lights), climate control, and automation technologies to optimize plant growth. By removing dependence on soil and weather conditions, vertical farms can operate in urban centers, reducing transportation costs and ensuring fresher produce. Hydroponics is generally more common due to its relative simplicity and lower cost, while aeroponics is gaining attention for its superior efficiency and faster growth rates. Together, they enable vertical farms to produce significantly higher yields per unit area compared to traditional agriculture.

Challenges and Future Prospects

Despite their advantages, both systems face challenges, including high initial setup costs, energy consumption for lighting and climate control, and the need for technical expertise. However, ongoing advancements in renewable energy integration, automation, and system design are gradually addressing these limitations. Looking ahead, hydroponics and aeroponics are expected to play a crucial role in ensuring food security, particularly in densely populated and climate-vulnerable regions. Their ability to produce more with fewer resources aligns well with the goals of sustainable agriculture and smart city development.

Conclusion

Hydroponics and aeroponics are not merely alternative farming methods; they are foundational technologies driving the future of agriculture. As vertical farming continues to expand globally, these soil-less systems will remain central to achieving efficient, sustainable, and scalable food production in the modern world.

Nanomaterials in Smart Fertilizers for Sustainable Agriculture

Muneshwar Prasad Mandal and Siddharth Kiran

Introduction

The growing global demand for food, coupled with declining soil fertility and environmental degradation, has intensified the need for more efficient and sustainable agricultural practices. Conventional fertilizers, although essential for crop productivity, suffer from low nutrient use efficiency, with a significant portion lost through leaching, volatilization, and runoff. This not only increases production costs but also leads to environmental pollution. In this context, nanotechnology has emerged as a promising solution, particularly through the development of nanomaterials-based smart fertilizers that enable precise and controlled nutrient delivery.

Concept of Nanomaterials in Fertilizers

Nanomaterials are materials with dimensions in the range of 1-100 nanometers, possessing unique physicochemical properties such as high surface area, enhanced reactivity, and tunable surface functionalities. When applied in fertilizers, these materials can encapsulate nutrients or bind them to nanoscale carriers, forming what are known as nano-fertilizers or smart fertilizers. These systems are designed to release nutrients in a controlled manner, synchronized with plant uptake, thereby significantly

improving nutrient use efficiency. Nanomaterials such as nano-clays, metal oxides (e.g., zinc oxide, iron oxide), carbon-based nanostructures, and polymeric nanoparticles are commonly used in these formulations. Their ability to interact at the cellular level enhances nutrient absorption and translocation within plants.

Mechanism and Advantages

The primary advantage of nanomaterial-based fertilizers lies in their controlled-release mechanism. Nutrients are either encapsulated within nanocarriers or coated with nanomaterials that regulate their dissolution. Environmental triggers such as soil pH, moisture, temperature, or root exudates can influence the release rate, ensuring that nutrients are available precisely when required by the plant. This targeted delivery minimizes nutrient losses and reduces the frequency of fertilizer application. Additionally, the high surface reactivity of nanomaterials improves nutrient solubility and uptake efficiency. As a result, lower quantities of fertilizers are needed to achieve the same or even higher crop yields compared to conventional methods. Another significant advantage is environmental sustainability. Reduced leaching and runoff lower the risk of water pollution and eutrophication.

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Moreover, the efficient use of nutrients helps in conserving non-renewable resources such as phosphate rock.

Applications in Sustainable Agriculture

Nanomaterials-based smart fertilizers are particularly beneficial in precision agriculture systems, where inputs are optimized based on real-time crop requirements. They are widely studied for delivering essential nutrients like nitrogen, phosphorus, potassium, and micronutrients such as zinc and iron. In addition, multifunctional nanomaterials can combine nutrient delivery with plant protection, acting as carriers for pesticides or growth stimulants. This integrated approach reduces chemical inputs and enhances overall crop health. Such innovations are especially relevant for addressing challenges in resource-limited and climate-stressed agricultural regions.

Challenges and Future Prospects

Despite their potential, the widespread adoption of nano-fertilizers faces several challenges. These include high production costs, scalability issues, and concerns regarding the long-term environmental and health impacts of nanomaterials. Regulatory frameworks for their safe use are still evolving, and more research is needed to assess their toxicity and biodegradability. However, ongoing advancements in materials engineering and green nanotechnology are paving the way for safer and more cost-effective solutions. The integration of nanomaterials with biodegradable polymers and natural carriers is a promising direction.

Conclusion

Nanomaterials in smart fertilizers represent a significant advancement toward sustainable agriculture. By enhancing nutrient efficiency, reducing environmental impact, and supporting precision farming, they offer a viable pathway to meet future food demands. With continued research and responsible implementation, nano-enabled fertilizers have the potential to transform modern agriculture into a more efficient and eco-friendly system.

From Tiny Wings to Healing Leaves: The Hidden Insect World behind Medicinal Plants

Divija S. D.

Abstract

Medicinal and aromatic plants are vital sources of natural healthcare, but their growth and productivity are closely influenced by insect interactions. While pollinators such as bees and butterflies play a crucial role in plant reproduction and yield enhancement, several insect pests cause significant damage, reducing both quality and production. This article highlights the dual role of insects in medicinal plant ecosystems, drawing on field-based examples from crops like giloe, ashwagandha, basil, and others. It emphasizes the importance of maintaining ecological balance through sustainable pest management practices to protect beneficial insects while controlling harmful ones. Understanding this relationship is essential for ensuring the long-term sustainability of herbal medicine systems.

Nature's Silent Workers: Pollinators

When we think of medicinal plants like Giloe, ashwagandha, basil, or shatavari, we often focus on their healing power. However, behind their growth lies an unseen world of insects. Among them, pollinators such as bees, butterflies, and flies play a vital role. Pollination is the process through which pollen is transferred from one flower to another, enabling fertilization. This ensures:

- ✓ Proper seed formation
- ✓ Better crop yield
- ✓ Improved plant vigor

Without pollinators, many medicinal plants would struggle to reproduce effectively.

A Closer Look at Field Reality

Field observations reveal that not all insects are beneficial. Many act as pests and cause serious damage to medicinal crops. In Giloe (*Tinospora*

cordifolia), grey weevils damage leaves by creating holes, while their grubs attack roots, leading to stunted growth. Fruit-sucking moth larvae can defoliate entire plants.

In *Gymnema sylvestre*, mealybugs and aphids suck plant sap, weakening plants and promoting sooty mould growth, which reduces photosynthesis.

Ashwagandha (*Withania somnifera*) is attacked by hadda beetles, spider mites, mealybugs, and cowbugs. These pests damage leaves, suck plant juices, and affect overall growth.

In basil (*Ocimum* spp.), lace bugs and leaf folders damage leaves and shoots, reducing plant vigor and essential oil production.

Similarly, senna, babchi, and shatavari face pest problems from caterpillars, pod borers, beetles, and leaf miners, all of which reduce yield and quality.

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The Delicate Balance

The presence of both beneficial and harmful insects highlights the need for ecological balance. While pollinators support plant reproduction, pests can reduce productivity if not managed properly. Overuse of chemical pesticides may control pests but can also harm pollinators, ultimately affecting crop yield and sustainability.

Towards Sustainable Solutions

To maintain healthy medicinal plant systems, the following practices are essential:

- ✓ Regular monitoring of pest activity
- ✓ Use of botanical pesticides like neem-based products
- ✓ Adoption of Integrated Pest Management (IPM)
- ✓ Conservation of natural enemies
- ✓ Promotion of biodiversity

These strategies help in protecting pollinators while minimizing pest damage.

From Field to Healing

Medicinal plants that reach our homes are the result of complex interactions between plants and insects. Pollinators ensure plant reproduction, while effective pest management maintains plant health.

Conclusion

Medicinal plants and insects share a close and dynamic relationship. Protecting beneficial insects while controlling harmful pests is essential for sustainable herbal production. A balanced ecosystem ensures the continued availability of high-quality medicinal plants.

Hidden Invaders: Survival Strategies of Intracellular Bacteria in Fish Diseases

Funde Aniket Raghunath and Isha Kumari

Abstract

Intracellular pathogenic bacteria are a major concern in fish health due to their ability to invade, survive, and replicate within host cells, leading to persistent and difficult-to-treat infections. Important fish pathogens such as *Edwardsiella tarda*, *Mycobacterium spp.*, *Piscirickettsia salmonis*, and *Francisella spp.* utilize specialized mechanisms to enter host cells through adhesion and invasion processes, including phagocytosis and endocytosis. Once inside, they adopt various survival strategies such as preventing phagosome-lysosome fusion, escaping into the cytoplasm, resisting oxidative stress through protective enzymes, and modulating host immune responses. These adaptations enable them to evade immune defenses and establish chronic infections. The impact on fish health includes granuloma formation, reduced growth, decreased productivity, and high mortality in severe cases. Moreover, their intracellular localization limits the effectiveness of antibiotics, making disease control challenging. Understanding these mechanisms is crucial for developing effective therapeutic and preventive strategies to manage intracellular bacterial infections in aquaculture.

Introduction

Fish health is crucial for aquaculture sustainability and food security. Among the many disease-causing agents, intracellular pathogenic bacteria are particularly dangerous because they can invade and live inside the host cells. This ability allows them to escape the immune system, persist for long periods, and cause chronic infections in fish. Once inside the host cell, these bacteria effectively evade immune detection, shielded from antibodies and many antimicrobial molecules circulating in bodily fluids. This intracellular lifestyle not only enables them to persist for extended periods but also facilitates chronic or recurrent infections that are difficult to treat using conventional antibiotics.

Furthermore, these pathogens manipulate the host's cellular machinery to create a favorable niche for their survival, altering immune responses, metabolism and even cell death pathways. Understanding how intracellular bacteria invade and persist within fish cells is therefore critical for developing effective disease management strategies, vaccines, and therapeutic interventions in aquaculture. Studying these hidden invaders also provides valuable insights into host-pathogen interactions and the evolutionary adaptations that enable bacterial survival within eukaryotic cells.

What are Intracellular Pathogenic Bacteria?

Intracellular pathogenic bacteria are a unique group of microorganisms that possess the remarkable

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ability to invade, survive, and replicate within the cells of their host, rather than living freely in extracellular environments. In fish, this group includes important pathogens such as *Edwardsiella tarda*, *Mycobacterium spp.*, *Piscirickettsia salmonis*, and *Francisella spp.*, all of which are responsible for significant economic losses in aquaculture. These bacteria have evolved specialized mechanisms that allow them to enter host cells particularly immune cells like macrophages, which are normally responsible for engulfing and destroying invading microbes. Instead of being eliminated, these pathogens manipulate the host cell's internal defense systems to create a favorable environment for their survival. They may inhibit the fusion of phagosomes with lysosomes, resist oxidative killing, or even escape into the cytoplasm, thereby avoiding degradation. This intracellular lifestyle not only provides them protection from the host's immune responses but also limits the effectiveness of many antibiotics, making infections persistent and difficult to treat. As a result, intracellular bacterial infections in fish are often chronic in nature, leading to reduced growth, increased susceptibility to secondary infections, and, in severe cases, high mortality rates.

Mechanism of Entry into Host Cells

The entry of intracellular pathogenic bacteria into fish host cells is a highly coordinated and specialized process that ensures successful establishment of infection. It begins with adhesion, where bacteria attach firmly to the surface of host cells using surface molecules known as adhesins.

These adhesins recognize and bind to specific receptors on the host cell membrane, allowing the pathogen to anchor itself securely despite the surrounding aquatic environment. This initial contact is crucial, as it determines host specificity and is the first step in colonization.

Following attachment, the bacteria actively promote their internalization through a process known as invasion. In immune cells such as macrophages, bacteria exploit the natural defense mechanism of phagocytosis, where the cell engulfs foreign particles. In contrast, in non-immune cells, pathogens induce endocytosis by triggering signaling pathways that cause the cell membrane to fold inward and engulf the bacteria. Many intracellular bacteria possess specialized proteins that manipulate the host cell's cytoskeleton particularly actin filaments facilitating their uptake. These proteins essentially "trick" the host cell into taking them inside. Once internalized, the bacteria reside within membrane-bound compartments, setting the stage for further survival and replication within the host cell.

Survival Strategies inside the Cell

Avoiding Phagosome-Lysosome Fusion: Under normal conditions, engulfed pathogens are destroyed when the phagosome fuses with a lysosome. However, intracellular bacteria can block this fusion process, preventing exposure to digestive enzymes. This allows them to survive safely within the host cell.

Escaping into Cytoplasm: Some bacteria have the

ability to break out of the phagosome and enter the cytoplasm. In this environment, they gain better access to nutrients and avoid many intracellular killing mechanisms, enhancing their survival and multiplication.

Resistance to Host Defenses: Intracellular pathogens produce protective enzymes such as catalase and superoxide dismutase. These enzymes neutralize reactive oxygen species generated by the host cell, helping the bacteria withstand oxidative stress.

Modulation of Host Immune Response: These bacteria can interfere with host cell signaling pathways to reduce inflammation and suppress immune responses. By doing so, they remain less detectable and can persist inside the host for longer durations.

Impact on Fish Health

Chronic Disease Conditions: Intracellular bacterial infections are usually long-lasting because the pathogens remain hidden within host cells. This leads to persistent, slow-progressing diseases that weaken fish over time.

Granuloma Formation: Infections, particularly those caused by *Mycobacterium spp.*, often result in the formation of granulomas localized nodular lesions formed as the immune system attempts to contain the bacteria. These lesions can damage vital organs.

Reduced Growth and Productivity: Affected fish show poor growth rates, reduced feed efficiency, and overall decline in health, which directly impacts

aquaculture productivity and economic returns.

High Mortality in Severe Cases: In advanced stages, especially under stress or poor management conditions, infections can lead to significant mortality in fish populations.

Difficult Treatment: These infections are challenging to control because antibiotics often fail to penetrate host cells effectively, allowing bacteria to survive and persist despite treatment.

Why are they Difficult to Control?

Intracellular bacterial infections in fish are particularly difficult to control because the pathogens reside safely within host cells, where they are protected from external threats. This intracellular location significantly reduces the effectiveness of antibiotics, as many drugs cannot adequately penetrate host cells to reach the bacteria. Additionally, these pathogens possess the ability to evade and manipulate the host's immune system, allowing them to avoid detection and destruction. Their capacity for long-term persistence further complicates control measures, as they can remain hidden within fish populations for extended periods, leading to recurring infections and making complete eradication extremely challenging.

Conclusion

Intracellular pathogenic bacteria represent a significant and often underestimated threat to fish health and aquaculture sustainability. Their unique ability to invade, survive, and multiply within host cells allows them to evade immune defenses, resist conventional treatments, and establish long-term

infections. By employing sophisticated strategies such as blocking phagosome–lysosome fusion, escaping into the cytoplasm, and modulating host immune responses, these pathogens create a protected niche that supports their persistence and spread. The resulting infections are typically chronic, difficult to diagnose, and challenging to control, leading to reduced productivity and economic losses. Therefore, a deeper understanding of their mechanisms of entry and survival is essential for the development of effective vaccines, targeted therapeutics, and improved disease management strategies. Strengthening biosecurity measures and advancing research in host–pathogen interactions will be key to mitigating the impact of these hidden invaders in aquaculture systems.

References

- Austin, B. and Austin, D. A. (2016) *Bacterial Fish Pathogens: Disease of Farmed and Wild Fish*. 6th edn. Cham: Springer.
- Roberts, R. J. (2012) *Fish Pathology*. 4th edn. Oxford: Wiley-Blackwell.
- Noga, E. J. (2010) *Fish Disease: Diagnosis and Treatment*. 2nd edn. Ames: Wiley-Blackwell.
- Fryer, J. L. and Hedrick, R. P. (2003) *Piscirickettsia salmonis*: a Gram-negative intracellular bacterial pathogen of fish. *Journal of Fish Diseases*, 26(5): 251-262.
- Soto, E., Hawke, J. P., Fernandez, D. and Morales, J. A. (2009) '*Francisella sp.*, an emerging pathogen of tilapia, *Oreochromis niloticus*', *Journal of Fish Diseases*, 32(9): 713-722.
- Secombes, C. J. and Wang, T. (2012) The innate and adaptive immune system of fish. *Fish & Shellfish Immunology*, 32(3): 293-298.
- Mohanty, B. R. and Sahoo, P. K. (2007). Edwardsiellosis in fish: a brief review. *Journal of Biosciences*, 32(7): 1331-1344.
- Pridgeon, J. W. and Klesius, P. H. (2012) Major bacterial diseases in aquaculture and their vaccine development. *CAB Reviews*, 7(048): 1-16.

Carrot Cultivation for Quality Root Production

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Introduction

Carrot (*Daucus carota* L.) is one of the most important root vegetable crops cultivated worldwide, valued for its high nutritional content, economic importance and adaptability to diverse agro-climatic conditions. It is an excellent source of β -carotene, a precursor of vitamin A, along with dietary fiber, minerals and antioxidants that contribute to human health. Carrot plays a vital role in addressing micronutrient deficiencies, particularly vitamin A deficiency, in developing countries. In India, carrot is cultivated in both tropical and temperate regions, with distinct varieties suited to each agro-climatic zone. Despite its significance, achieving high-quality root production remains a challenge due to factors such as improper soil conditions, nutrient imbalances, poor irrigation management, pest and disease incidence and inadequate cultural practices. Quality root production in carrot is characterized by uniform size and shape, smooth surface, deep color, tenderness, high carotene content and absence of defects such as forking, cracking and bitterness. Therefore, the adoption of improved cultivation practices is essential to enhance both yield and quality.



season crop that performs best under moderate temperatures ranging from 15°C to 25°C. Optimal temperature is crucial for proper root development, color formation and sweetness. High temperatures can lead to poor color development, increased fiber content and reduced root quality, while very low temperatures may cause bolting in certain varieties. Adequate sunlight is necessary for photosynthesis and carbohydrate accumulation in roots. Carrot requires a well-distributed rainfall or irrigation supply, as moisture stress can adversely affect root growth and quality.

Soil Requirements and Land Preparation: Soil plays a critical role in determining the quality of carrot roots. Well-drained sandy loam or loamy soils with a loose, friable structure are ideal for root elongation and uniform development. Heavy clay soils or compacted soils restrict root growth and lead to deformities such as forking and stunting. The optimal soil pH ranges from 6.0 to 7.0. Proper land preparation involves deep ploughing and fine tilth to ensure a smooth soil profile free from stones and clods. Raised beds or ridges are recommended to improve drainage and facilitate root development. Incorporation of well-decomposed organic matter enhances soil structure and microbial activity, contributing to better root quality.

Agro-Climatic Requirements: Carrot is a cool-

Selection of Varieties and Hybrids: The choice of

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suitable varieties is essential for achieving high-quality root production. Tropical varieties such as Pusa Kesar and Pusa Rudhira are well adapted to Indian conditions, while temperate varieties such as Nantes and Chantenay are preferred in cooler regions. Improved hybrids with uniform root shape, deep color and high carotene content are increasingly being adopted. Varieties resistant to bolting and diseases are desirable for maintaining yield and quality.

Seed Treatment and Sowing: Quality seed and proper sowing practices are fundamental for uniform crop establishment. Seeds should be treated with fungicides or biological agents such as *Trichoderma* spp. to prevent seed-borne diseases. Direct sowing is commonly practiced, as carrot does not tolerate transplanting well. Seeds are sown in rows at appropriate spacing to avoid overcrowding, which can lead to competition and poor root development. Thinning is necessary after germination to maintain optimal plant population and ensure uniform root growth.

Nutrient Management for Root Quality: Balanced nutrient management is critical for achieving high-quality carrot roots. Nitrogen promotes vegetative growth, but excessive nitrogen can lead to lush foliage at the expense of root development and may reduce sugar content. Phosphorus is important for root development, while potassium enhances root quality, color and storage life. Integrated nutrient management involving organic manures, chemical fertilizers and biofertilizers improves soil fertility

and nutrient use efficiency. Micronutrients such as boron are essential for preventing physiological disorders like root cracking and poor development. The application of organic manures such as farmyard manure or compost improves soil structure and enhances microbial activity, which positively influences root quality.

Irrigation Management: Proper irrigation management is essential for uniform root development and quality. Carrot requires consistent soil moisture, particularly during germination and root enlargement stages. Both water stress and excess moisture can adversely affect root quality. Water stress may lead to reduced root size and increased bitterness, while excess moisture can cause cracking and rotting. Drip irrigation is an efficient method that provides uniform moisture and reduces water wastage. Irrigation scheduling should be based on soil moisture status and crop growth stage to ensure optimal conditions for root development.

Weed Management: Weeds compete with carrot plants for nutrients, water and light, particularly during early growth stages. Effective weed management is essential to ensure healthy crop growth and high-quality root production. Integrated approaches such as manual weeding, mulching and the use of selective herbicides can be employed. Maintaining a weed-free environment during the initial stages of crop growth is crucial for achieving optimal yield and quality.

Integrated Pest Management (IPM): Carrot is susceptible to several pests, including aphids, carrot

fly and nematodes. These pests can cause significant damage to roots and reduce market quality. Integrated pest management strategies involve the use of resistant varieties, crop rotation, biological control agents and botanical pesticides. The use of pheromone traps and sticky traps helps monitor pest populations. Chemical pesticides should be used judiciously to minimize environmental impact and avoid residue problems.

Disease Management: Major diseases affecting carrot include leaf blight, powdery mildew and root rot. Integrated disease management practices include the use of disease-free seeds, proper crop rotation, field sanitation and biological control agents. Maintaining proper spacing and avoiding excessive irrigation reduce humidity and minimize disease incidence. Seed treatment and soil application of bioagents such as *Trichoderma* spp. are effective in controlling soil-borne diseases.

Physiological Disorders and their Management: Carrot roots are prone to several physiological disorders that affect quality, including forking, cracking, greening and bitterness. Forking is often caused by soil compaction or the presence of undecomposed organic matter, while cracking results from irregular irrigation. Greening occurs when roots are exposed to sunlight, leading to chlorophyll formation and reduced quality. Proper soil preparation, uniform irrigation and adequate soil coverage of roots can help prevent these disorders.

Harvesting and Yield: Carrots are ready for harvest when roots attain the desired size, color and tender-

ness. Timely harvesting is essential to prevent over-maturity, which can result in fibrous and less palatable roots. Harvesting is usually done manually by loosening the soil and pulling out the roots. Improved cultivation practices can significantly enhance yield, with potential yields ranging from 25 to 40 tonnes per hectare depending on the variety and growing conditions.

Post-Harvest Handling and Storage: Post-harvest handling plays a crucial role in maintaining root quality and reducing losses. Harvested roots should be washed, graded and trimmed to remove tops and damaged portions. Storage under low temperatures and high humidity helps maintain freshness and prolong shelf life. Proper packaging and transportation are essential to prevent mechanical damage and maintain quality during marketing.

Constraints and Challenges: Carrot cultivation faces challenges such as poor soil conditions, pest and disease incidence, climatic variability and lack of access to quality inputs. Improper irrigation and nutrient management can lead to poor root quality and reduced yield. Addressing these challenges requires the adoption of improved cultivation practices and technologies.

Future Prospects

The future of carrot cultivation lies in the adoption of climate-smart and precision agriculture practices. The development of high-yielding, disease-resistant varieties and the use of advanced irrigation and nutrient management techniques will enhance productivity and sustainability. Research on

improving carotene content and root quality will further increase the nutritional value of carrots.

Conclusion

Carrot cultivation for quality root production requires a comprehensive approach that integrates proper soil management, balanced nutrition, efficient irrigation and effective pest and disease control. The adoption of improved cultivation practices can significantly enhance yield, root quality and profitability. With increasing demand for nutritious and high-quality vegetables, carrot cultivation offers great potential for improving food security and farmers' livelihoods. Sustainable and scientific production practices will play a key role in achieving consistent and high-quality carrot production.

References

- Rubatzky, V. E., Quiros, C. F. and Simon, P. W. (1999). Carrots and Related Vegetable Umbelliferae. CABI Publishing.
- Singh, B., Kumar, M. and Singh, R. K. (2017). Advances in root vegetable production. *International Journal of Agriculture Sciences* 9(45): 4721-4725.
- Kumar, S., Singh, R. and Verma, A. K. (2020). Improved cultivation practices in carrot. *Vegetable Science*, 47(2): 145-152.
- Meena, R. S., Kumar, S. and Meena, V. S. (2019). Nutrient management in vegetable crops. *Agricultural Reviews*, 40(3): 181-188.

Nutritional Power of Millets: A Superfood for Rural and Urban Diets

Abhishek Shaw and Varsha Rani

Abstract

Long marginalized by the rapid expansion of wheat and rice cultivation during the Green Revolution, millets are currently experiencing a powerful global resurgence as vital “nutri-cereal”. These ancient, small-seeded grasses occupy a unique position in modern agriculture, offering an exceptional intersection of dense nutritional value and profound climate resilience. This article provides a comprehensive overview of both major and minor millets, detailing their rich dietary profiles which boast significantly higher levels of essential minerals, dietary fibre, and protective phytochemicals compared to standard refined grains. Furthermore, the review explores the dual socio-economic impact of these versatile crops. While millets continue to anchor food and livelihood security in rural, drought-prone regions, they are simultaneously capturing the attention of health-conscious urban consumers through innovative, value-added food products. Finally, the paper underscores the critical role of millets in advancing climate-smart agriculture due to their minimal water and fertilizer requirements, highlighting recent governmental and global initiatives designed to strengthen their research, production, and broader market value chains.

Introduction

Millets are among the oldest cereal crops known to humankind and have been grown for thousands of years throughout Asia and Africa. These small-seeded grains have traditionally become the backbone of food systems in many semi-arid locations where other crops struggle to grow. Despite their long history, millets eventually lost popularity with the rise of rice and wheat cultivation during the Green Revolution. However, in recent years, millets have regained interest because of their remarkable nutritional content, climate resilience, and possible significance in assuring food security. Recognizing

their global importance, the United Nations announced International Year of Millets 2023, an initiative backed by the Food and Agriculture Organization, to promote awareness of millets as healthy and sustainable crops. Today, millets are increasingly referred to as “nutri-cereals” or “superfoods” because of their nutritional as well as therapeutic values (Kumar *et al.*, 2018). Millets have always been an essential component of rural diets, but they are becoming very popular again in urban kitchens as health-conscious people look for alternatives to processed cereals. Their versatility, nutritional richness, and environmental sustainability make

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millets highly relevant for both rural and urban populations.

Major Types of Millets

Millets consist of several species belonging to the grass family (Poaceae). They are extensively cultivated in dryland regions due to their lower water and agricultural input requirements in comparison to major cereals. The most important millets grown in India include Pearl millet, Finger millet, and Sorghum, often referred to as major millets. In addition, several minor millets are also cultivated, including Foxtail millet, Little millet, Barnyard millet, Kodo millet, and Proso millet. These crops are particularly suitable for marginal lands and rainfed agriculture. Their ability to tolerate drought, high temperatures, and poor soil fertility makes them valuable crops for farmers in semi-arid and arid regions (Rao *et al.*, 2017).

Table 1. Mineral composition of Major Millets (in mg/100 g)

Mineral composition of Major Millets (in mg/100g)					
Millet	Iron	Calcium	Zinc	Phosphorus	Magnesium
Sorghum	3.9	27.6	1.9	274	133
Pearl Millet	6.4	27.4	2.8	289	124
Finger Millet	4.6	364	2.5	210	146

(Source: DoA&FW. 2023. Brief notes on millets. Department of Agriculture and Farmers' Welfare, Ministry of Agriculture and Farmers Welfare, India. 20 pp.)

Nutritional Richness of Millets

Millets are often described as “nutritional powerhouses” because they contain a wide range of essential nutrients required for human health. Compared with refined cereals such as polished rice,

millets offer significantly higher levels of dietary fiber, minerals, and bioactive compounds. For instance, finger millet is exceptionally rich in calcium, while pearl millet provides high levels of iron and protein. Foxtail millet and barnyard millet are particularly rich in dietary fiber and antioxidants. Millets also contain important vitamins such as thiamine, riboflavin, and niacin (Saleh *et al.*, 2013). Another important nutritional advantage of millets is the presence of phytochemicals such as polyphenols and flavonoids. These compounds possess antioxidant properties that help protect the body against oxidative stress and chronic diseases

Table 2: Nutritional comparison of millets with common cereals (Source: DoA&FW, 2023)

Crop	Protein (%)	Fiber (%)	Carbohydrate (%)	Fat (%)
Millets (average)	7-11	7-11	65-75	2-5
Wheat (average)	11-13	2-3	70-75	1.5-2
Rice (average)	6-7	0.5-1	75-80	0.5

Health Benefits of Millet Consumption

Regulation of blood glucose levels: Millets possess a low glycemic index, which enables a slower release of glucose into the bloodstream. This property helps maintain stable blood sugar levels and makes millets particularly beneficial for individuals affected by Type 2 Diabetes (Anitha *et al.*, 2021).

Improvement of cardiovascular health: The high dietary fiber content present in millets contributes to the reduction of serum cholesterol levels and supports improved lipid metabolism. These effects may lower the risk of developing Cardiovascular Disease. Additionally, naturally occurring antioxi-

nts in millets help reduce inflammation and support overall metabolic balance.

Support in weight management: Millets are rich in dietary fiber, which enhances satiety and reduces excessive food intake. This characteristic can assist in controlling body weight and may help prevent Obesity when incorporated into regular diets.

Suitability for gluten-free diets: Millets are naturally gluten-free, making them an excellent dietary alternative for individuals with gluten intolerance or those diagnosed with Celiac Disease.



Figure 1. Role of Millets in Human Health

Millets in Rural Food Systems

Millets have long been the primary diet for rural people in many parts of India. In rainfed and drought-prone locations, farmers have relied on millets for both subsistence and income generation. Traditional meals like as millet rotis, porridges, and fermented liquids remain key components of rural diets. Millets offer affordable nutrition and can grow well in regions where crops such as rice and wheat may fail. Their low input requirements also cut production costs, making them suited for small and marginal farms. Furthermore, millet farming contributes to rural livelihood security by providing

food, fodder, and revenue opportunities. In many tribal and dryland locations, millets continue to play an important function in sustaining dietary diversity and nutritional security.

Emerging Role of Millets in Urban Diets

In recent years, millets have gained popularity among urban people who are conscious about healthy eating and lifestyle diseases. Nutritionists and health experts often recommend the incorporation of whole grains such as millets in regular diets. Food individuals and entrepreneurs are also responding to this increased demand by creating a wide range of millet-based goods. These include millet cookies, breakfast cereals, noodles, snack foods, and ready-to-cook mixes. Restaurants and cafes are experimenting with creative recipes such as millet salads, millet spaghetti, and millet sweets. This increased urban demand has generated new market prospects for farmers and food processors, ultimately boosting the millet value chain.



Millets and Sustainable Agriculture

Beyond their nutritional benefits, millets also contribute significantly to environmental sustainability. They require far less water than major cereals and can grow in poor soils with minimal fertilizer application. These characteristics make millets

particularly valuable under the framework of Climate-Smart Agriculture. Millets also have a short growing season and are relatively resistant to pests and diseases, reducing the need for chemical pesticides. As a result, millet cultivation can help promote eco-friendly farming practices while conserving natural resources. By encouraging millet production, farmers can diversify cropping systems, improve soil health, and increase resilience to climate variability.

Government Initiatives Promoting Millets

In recent years, governments and research institutions have increased their focus on promoting millets due to their importance for nutrition, climate resilience, and sustainable agriculture. Earlier, research investments were largely concentrated on major cereals such as wheat, rice, and maize, while millets received limited attention. To address this gap, greater emphasis is now being placed on research and development (R&D), genetic improvement, and technological innovation to enhance millet productivity.

Government initiatives support the development of high-yielding and stress-tolerant millet varieties, establishment of seed hubs, and promotion of improved cultivation and processing technologies. These efforts aim to reduce labour intensity, particularly for rural women, and increase farmers' adoption of millets. Policies also encourage the development of value-added millet-based foods, strengthening supply chains and market opportunities. At the global level, the Millets and Other

Ancient Grains International Research Initiative (MAHARISHI), launched by G20 agricultural scientists, promotes international collaboration in millet research. Together with the momentum of the International Year of Millets 2023, these initiatives aim to improve productivity, promote consumption, and strengthen the global millet value chain

Conclusion

Millets represent an important group of cereal crops that integrate high nutritional value with ecological sustainability. Their rich composition of proteins, dietary fibre, essential minerals and bio-active antioxidants contributes significantly to improving human nutrition and overall health. In addition, their ability to withstand adverse environmental conditions, including drought, poor soils, and climatic variability, makes them highly suitable for climate-resilient and sustainable agricultural systems. Although millets have historically been considered a staple in rural diets, their growing acceptance among urban populations indicates a renewed recognition of their nutritional and health benefits. Consequently, the promotion of millet cultivation and consumption can play a crucial role in addressing major global challenges such as malnutrition, climate change, and livelihood security for smallholder farmers. With continued research, policy support, and consumer awareness, millets have the potential to become a key component of healthy diets and sustainable food systems in the future.

References

- Anitha, S., Kane-Potaka, J., Tsusaka, T., Botha, R. and Rajendran, A. (2021). Millets can have a major impact on improving iron status and reducing iron deficiency anemia. *Frontiers in Nutrition*, 8: 725529.
- DoA&FW. (2023). Brief notes on millets. Department of Agriculture and Farmers' Welfare, Ministry of Agriculture and Farmers Welfare, India. p.20.
- Kumar, A., Tomer, V., Kaur, A., Kumar, V., & Gupta, K. (2018). Millets: A solution to agrarian and nutritional challenges. *Agriculture & Food Security*, 7(1): 31.
- Maurya, R., Boini, T., Misro, L., Radhakrishnan, T., Sreedharan, A. P. and Gaidhani, D. (2023). Comprehensive Review on Millets: Nutritional Values, Effect of Food Processing and Dietary Aspects. *Journal of Drug Research in Ayurvedic Sciences*, 8(Suppl 1): S82-S98.
- Rao, B. D., Bhaskarachary, K., Christina, G. D., Devi, G. S. and Tonapi, V. A. (2017). Nutritional and health benefits of millets. Indian Institute of Millets Research, Hyderabad.
- Saleh, A. S. M., Zhang, Q., Chen, J. and Shen, Q. (2013). Millet grains: Nutritional quality, processing, and potential health benefits. *Comprehensive Reviews in Food Science and Food Safety*, 12(3): 281-295.

Carbon Sequestration Capabilities of Sal Forests and Its Site-Specific Management Strategies

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Abstract

Sal (*Shorea robusta* Gaertn. f.) forests represent one of the most extensive tropical deciduous forest ecosystems in South Asia and play a critical role in climate change mitigation through long-term carbon sequestration in biomass and soil. Their high biomass production, structural stability, and ecological resilience enhance their capacity to buffer climatic variability and sustain ecosystem functioning. This synthesis integrates existing knowledge on biomass carbon, soil organic carbon, litter and detritus dynamics, and the influence of site quality and management on carbon storage in Sal forests. Evidence from compartment-level assessments demonstrates significant variation in biomass and ecosystem carbon density across site qualities, highlighting the importance of stand-specific conditions in regulating carbon dynamics. The review further discusses key challenges in carbon estimation and emphasizes the need for compartment-specific management to enhance the mitigation potential and sustainability of Sal forest ecosystems.

Introduction

Forests are among the most important terrestrial carbon sinks, storing a substantial proportion of global above-ground and soil organic carbon. Tropical forests, in particular, play a disproportionate role in regulating atmospheric carbon dioxide due to their high productivity and biomass density. In South Asia, Sal (*Shorea robusta* Gaertn. f.) forests occupy extensive areas across central India, the Himalayan foothills, eastern India, and parts of Nepal, forming the ecological backbone of many forested landscapes. Sal forests are characterized by dominance of a high wood-density species, long life span, and relatively stable stand

structure under protected conditions. These traits make them efficient long-term carbon reservoirs. Increasing emphasis on climate mitigation strategies, including REDD+ and national greenhouse gas inventories, has intensified the need for reliable estimates of carbon sequestration potential in Sal-dominated ecosystems. However, wide variability in reported carbon stocks reflects differences in site quality, disturbance regime, stand age, and methodological approaches, necessitating a synthesis that integrates ecological drivers with empirical evidence.

Biomass Carbon Storage in Sal Forests

Above-ground biomass constitutes the largest

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and most dynamic carbon pool in Sal forests. High wood density, dominance of mature individuals, and relatively slow turnover rates contribute to substantial carbon accumulation in stems, branches, and foliage. Several studies have shown that tree biomass accounts for the major proportion of ecosystem carbon in Sal forests, particularly in mature and less-disturbed stands (Sharma *et al.*, 2011; Chaturvedi *et al.*, 2011). Stand structure parameters such as basal area, tree density, and diameter class distribution exert strong control over biomass carbon storage. Site quality further modulates these relationships by influencing productivity and biomass increment. Empirical evidence from compartment-level assessments across different site qualities indicates that total biomass in Sal forests can vary widely, ranging from 123.89 to 487.35 Mg ha⁻¹, while vegetation carbon density ranges from 89.89 to 234.26 Mg C ha⁻¹, reflecting strong site- and stand-specific effects (Sharma *et al.*, 2025). Some compartments consistently exhibit higher biomass and vegetation carbon density, underscoring the role of favorable site conditions in enhancing above-ground carbon sequestration.

Below-ground biomass, comprising coarse and fine roots, contributes a substantial fraction of total ecosystem carbon but remains comparatively under-studied. In Sal forests, below-ground carbon typically represents 15-30% of total tree biomass carbon, with fine root turnover serving as a key pathway for carbon transfer to soil pools (Singh and Singh, 1991). Variations in ecosystem carbon dens-

ity, ranging from 114.53 to 287.58 Mg C ha⁻¹, further indicate that differences in below-ground inputs and soil carbon stabilization processes are closely linked to above-ground productivity and site quality (Sharma *et al.*, 2025).



Soil Organic Carbon and Forest Floor Dynamics

Soil organic carbon (SOC) constitutes one of the most stable and long-term carbon pools in Sal forest ecosystems. SOC accumulation is strongly influenced by litter quality, decomposition rates, soil texture, and moisture regime. Sal leaf litter, characterized by high lignin and polyphenolic content, decomposes slowly, promoting the retention of organic matter in the forest floor and mineral soil (Lal, 2005). Seasonal litterfall represents a major input of organic carbon, with peak deposition occurring during the dry season. Forest floor components including leaf litter, dead twigs and branches, and partially decomposed organic matter act as transitional carbon pools linking biomass production with soil carbon sequestration. Significant inter-compartmental variation in leaf litter, dead wood and total detritus biomass density has been observed even among compartments sharing the same site quality, emphasizing the influence of stand-level heterogeneity on detrital carbon storage (Sharma *et al.*, 2025).

Soil analyses reveal that both labile and non-labile organic carbon fractions are closely associated with site quality. Maximum values of these fractions have been reported in high-carbon compartments with Site quality (SQ) II, while minimum values occur in lower-quality sites (SQ-III) (Sharma *et al.*, 2025). Additionally, SOC concentrations decline significantly with soil depth, with higher carbon content in the 0-20 cm layer compared to the 20-40 cm layer, reflecting reduced organic inputs and biological activity at greater depths.

Influence of Nutrients, Disturbance and Management

Soil nutrient availability plays a critical role in regulating forest productivity and carbon sequestration. In Sal forests, available nitrogen, phosphorus, and potassium show strong associations with site quality and carbon-rich compartments, reinforcing the link between nutrient status and biomass accumulation (Sharma *et al.*, 2025). In contrast, micronutrients such as Zn, Fe, B, and Cu generally exhibit limited spatial variation, suggesting a lesser role in controlling large-scale carbon dynamics. Anthropogenic disturbances, including selective logging, grazing, fuelwood extraction, and forest fires, significantly reduce carbon sequestration potential by altering stand structure, litter inputs, and soil properties. Degraded Sal forests consistently exhibit lower biomass and reduced ecosystem carbon density compared to protected stands (Negi *et al.*, 2018). Conversely, effective protection, assisted natural regeneration, and site-specific silvicultural

interventions can substantially enhance biomass recovery and long-term carbon storage. Evidence indicates that compartment-specific management, rather than uniform prescriptions, is essential for maximizing carbon sequestration across heterogeneous Sal forest landscapes (Sharma *et al.*, 2025).

Challenges in Carbon Assessment

Despite increasing research attention, several challenges constrain accurate assessment of carbon sequestration in Sal forests. These include methodological variability in biomass estimation, limited direct measurement of below-ground carbon pools, and pronounced spatial heterogeneity across site qualities and disturbance gradients. Additionally, long-term data on the effects of climate variability particularly changes in rainfall patterns and temperature extremes on Sal forest carbon dynamics remain scarce. Addressing these challenges will require standardized protocols, permanent sample plots, and integration of field measurements with remote sensing and modeling approaches.

Conclusion

Sal forests constitute a robust and resilient carbon sink within the tropical deciduous forest landscapes of South Asia. High biomass accumulation, substantial soil organic carbon storage, and slow carbon turnover rates confer significant climate mitigation potential. However, carbon sequestration capacity varies markedly across site qualities and forest compartments, even within similar ecological classes. Empirical evidence highlights the necessity of compartment-specific management strategies to

enhance biomass productivity, carbon storage, and ecosystem sustainability. Strengthening long-term monitoring and integrating site-quality considerations into forest management and climate policy frameworks will be critical for realizing the full mitigation potential of Sal forest ecosystems.

References

- Chaturvedi, R. K., Raghubanshi, A. S. and Singh, J. S. (2011). Carbon density and accumulation in woody species of tropical dry forests in India. *Forest Ecology and Management*, 262: 1576-1588.
- Lal, R. (2005). Forest soils and carbon sequestration. *Forest Ecology and Management*, 220: 242-258.
- Negi, G. C. S., Samal, P. K. and Kuniyal, J. C. (2018). Impact of disturbance on biomass and carbon storage in tropical Sal forests. *Environmental Monitoring and Assessment*, 190: 1-14.
- Sharma, C. M., Gairola, S. and Baduni, N. P. (2011). Variation in carbon stocks of Sal forests under different management regimes in Uttarakhand, India. *Tropical Ecology*, 52: 335-346.
- Singh, L. and Singh, J. S. (1991). Storage and flux of nutrients in a dry tropical forest in India. *Annals of Botany*, 68: 275-284.

Women Empowerment in Sericulture

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Abstract

Sericulture is a vital agro-based industry that significantly contributes to rural livelihoods and employment generation, particularly in countries like India. This article examines the role of women in sericulture and its impact on their empowerment. Women are actively involved in all stages of silk production, including mulberry cultivation, silkworm rearing, cocoon harvesting, and silk reeling. Their participation enhances productivity, ensures quality output, and provides a reliable source of income for rural households. Sericulture enables women to balance domestic responsibilities with income-generating activities, thereby promoting financial independence and improving family welfare. It also encourages participation in self-help groups and skill development programs, strengthening their confidence and decision-making abilities. Despite facing challenges such as limited access to resources and training, sericulture remains a powerful tool for women empowerment, poverty alleviation, and sustainable rural development.

Introduction

Sericulture, the cultivation of silkworms for silk production, is an important agro-based industry that combines agriculture and cottage-level processing. In countries like India, it plays a vital role in rural livelihoods and employment generation, especially for small and marginal farmer. This industry provides regular income, making it suitable for rural households. A key feature of sericulture is the extensive participation of women. Women are involved in almost all stages of silk production, including mulberry cultivation, silkworm rearing, cocoon harvesting and silk reeling. Their work requires patience, care and skill, particularly in maintaining proper feeding and environmental conditions for silkworms.

In many regions, women form the majority of the workforce in this sector. Sericulture also provides women with opportunities for economic independence and empowerment. Since many activities can be carried out at home or nearby, women can manage both household responsibilities and income-generating work. Their earnings contribute to family welfare and improve living standards. Thus, sericulture is not only an economic activity but also a means of empowering women and promoting sustainable rural development.

Women in Mulberry Cultivation

Mulberry cultivation forms the foundation of sericulture, as mulberry leaves are the primary food

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source for silkworm. Women are actively involved in various field operations such as planting, irrigation, weeding, pruning and leaf harvesting. Their consistent efforts ensure the availability of fresh and nutritious leave, which directly influence the growth and health of silkworms. Studies have shown that women contribute a major share of labour in mulberry fields, particularly in small and marginal farming systems.

Role in Silkworm Rearing

Silkworm rearing is a delicate and skill-intensive process requiring constant care and attention. Women play a dominant role in this stage by feeding silkworms at regular intervals, maintaining cleanliness in rearing houses and monitoring environmental conditions such as temperature and humidity. Their patience and precision help in reducing disease incidence and improving cocoon quality. The studies showed that women's involvement in silkworm rearing significantly enhances productivity and better yield.

Contribution to Cocoon Harvesting and Processing

After the completion of the larval stage, silkworms spin cocoons, which are harvested and processed for silk extraction. Women are primarily responsible for sorting, grading and storing cocoon. In addition, they actively participate in reeling and spinning processes, where silk threads are carefully unwound from cocoons. These activities require fine motor skills and attention to detailing, making women particularly suited for such tasks.

Economic Importance and Livelihood Support

Sericulture provides a reliable source of income for rural households and women's participation greatly enhances family earnings. Since it is a labour-intensive activity that does not demand heavy physical work, it is well-suited for women, allowing them to balance household responsibilities with income-generating activities. In many region, women contribute more than 50 % of the total workforce in sericulture, thereby playing a key role in poverty alleviation and rural development.

Women Empowerment through Sericulture

Beyond economic benefit, sericulture has a profound social impact by empowering women. It promotes self-employment, encourages participation in self-help group and enhances decision-making abilities. Government programs and training initiatives help women acquire technical knowledge and entrepreneurial skills. As a result, many women become financially independent and gain confidence in managing both household and professional responsibilities.

Challenges Faced by Women

Despite their significant contributions, women in sericulture face several challenges, including lack of access to resources, limited technical training and inadequate recognition of their work. In some cases, gender-based disparities in wages and decision-making persist. Addressing these issues through policy support, education and inclusive programs is essential for maximizing women's potential in this sector.

Conclusion

Women are the backbone of the sericulture industry, contributing at every stage from mulberry cultivation to silk production. Their dedication, patience and skill ensure the smooth functioning and sustainability of this sector. From nurturing mulberry plants to carefully rearing silkworms and processing cocoons, women play a vital role in maintain both the quality and productivity of silk. Beyond their technical contribution, sericulture has a significant impact on the socio-economic status of women, particularly in countries like India. It provides them with regular income, enhances financial independence and improves their participation in household decision-making. This, in turn, leads to better education, health and overall well-being of their families. Furthermore, sericulture promotes women's empowerment by encouraging their involvement in self-help groups, training programs, and small-scale enterprises. It helps build confidence, leadership qualities and entrepreneurial skills among rural women. However, to fully realize their potential, there is a need to strengthen support systems through better access to training, credit facilities, modern technologies, and market linkages. Recognizing and valuing women's contributions will not only boost the growth of the sericulture industry but also ensure inclusive and sustainable rural development.

References

- Bukhari, R., Kour, H. and Aziz, A. (2019). Women and the Indian sericulture industry. *International Journal of Current Microbiology and Applied Sciences*, 8(05): 2319-7706.
- Shravanilakshmi, V., Kruthika, S., Shwetha, V. and Veenita, K. (2025). Sericulture as a Tool for Rural Development and Women Empowerment. *Journal of Experimental Agriculture International*, 47(9): 66-77.
- Yadav, U. and Jadhav, N. (2017). Empowerment of rural women through sericulture. *Environment Conservation Journal*, 18(1&2): 207-209.

Fish Surimi: Process and Value-Added Products

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Introduction

Due to declining marine catch and rising consumer demand for fish products, it has become increasingly important to fully exploit fish landings, especially underutilised fish species, as human food. Although there are many ways to add value to fish, surimi technology has been identified as one of the most effective ways to use fish at a minimal cost. A common culinary item in East Asian cuisines, surimi can be found in a variety of sizes and shapes, from fish balls to different types of seafood imitations, such as crab sticks. Fish meat that has been deboned, minced, and cleaned is used to make surimi. Highly processed seafood products known as surimi are created by removing soluble proteins, lipids, colours, and odorous chemicals from fish flesh. These products can then be frozen by adding cryoprotectants (CP). In reality, it should be considered an intermediate product as, when thawed, it serves as the foundation for traditional Japanese products like “kamaboko,” which are generally referred to as “neriseihin,” through a variety of heating techniques like steaming, frying, and broiling and a variety of more recent products (such as shellfish analogues or crab sticks)

Fish Muscle Protein

Sarcoplasmic proteins are water-soluble and physiologically active molecules (enzymes and oxygen carriers), they might cause instability when they are liberated from certain cell structures by disruptive procedures like filleting, mincing, or other processing unit operations. They don't help with gel formation, and in fact, the proteases can reduce the capacity to gel by breaking down the myofibrillar proteins. The primary goal of the surimi process is to eliminate the sarcoplasmic proteins, which make up 18-20% of all muscle protein. The main goal of the surimi process is to remove the sarcoplasmic proteins, which make up 18-20% of all muscle protein. Myosin, actin, tropomyosin, and troponin are the myofibrillar proteins that make up the majority of muscle protein (65-80% of total muscle protein). Because these proteins can form gel when heated, they contribute to the texture of both natural fish flesh and items made from surimi.

The other main goal of the surimi process is the recovery of these concentrated proteins and their preservation after freezing. The stroma and connective tissue proteins, which make up only 3-5% of the total muscle protein in fish (unlike terrestrial animals) and contain collagen and elastin, are the most durable proteins. They are not usually totally

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eliminated throughout the surimi process; instead, they become “neutral” components in the finished product after being dissolved by the heating process.

Surimi Processing

Raw Material: The quality of the raw materials is essential while making surimi. High-quality raw materials yield the best gel character and bland colour since there is less autolysis of native proteins and less contamination with blood and intestinal residues (Fig. 1).

Pre-processing: All the conventional pre-processing operations take place (heading, gutting, skinning, filleting and washing), and then this material is put through the deboner/separator for further separation of components of the original fish. By these means, the overall yield of the process might be only 18-36% of the original and so the recovery and use of the process wastes is essential (Fig. 1).

Washing process: It is at the centre of the surimi process, giving rise to the original product concept by removal of more components of the raw material: the water-soluble non-gel-forming proteins, proteolytic enzymes, pigments and blood, and lipids and lipid oxidation promoting haem compounds (Fig. 1).

The refiner/strainer and dehydrator: These stages are all designed to remove fine bones and skin and then water from the proteins to give the best gel-forming capability (Fig. 1).

Addition of CP: It was not a part of the traditional process but important for the industrial process where frozen storage has made large-scale product-

ion feasible. The traditional CPs were sucrose (4%), sorbitol (4%) and polyphosphates (0.3%) although a wider range is used today (Fig. 1).

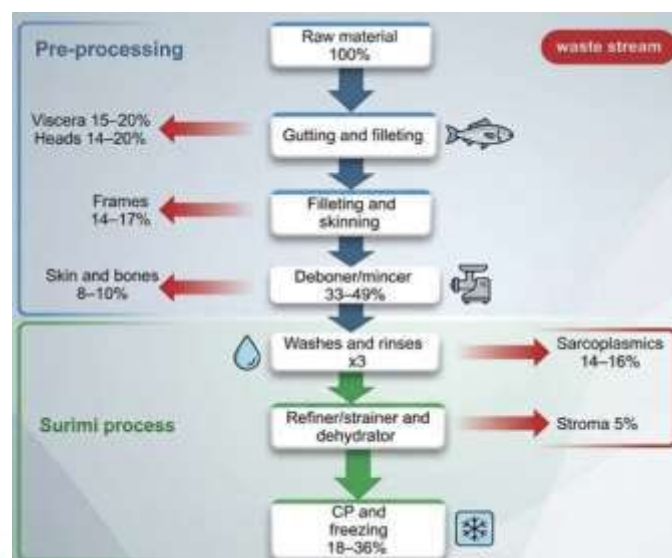


Fig. 1: Surimi Processing

Species used for surimi processing

Lean white fish is used for a traditional surimi because it is easier to produce a bland colour and has a bland taste because it has less lipids that need to be eliminated. Numerous alternative species have been tested due to the growing pressure on Alaska pollock (*Theragra chalcogramma*), the traditional species used for surimi in Japan. The variety of species studied has expanded since the invention of the mechanical flesh-bone separator, which made it possible to employ additional raw materials from small fish or bycatch.

Products of surimi

Kamaboko: Usually shaped like a loaf, kamaboko are steamed, then sliced and served cold with dipping sauces or added to hot soups and chikama, a cheese-topped



snack. Certain shapes have historic patterns of colour that represent regional manufacture. Eaten raw and frequently in salads, crab sticks are a type of kamaboko (kanikama) flavoured with crab, food colouring, and egg white. Eomuk or odeng, a street dish boiled in broth, is a South Korean variation of kamaboko.

Hanpen: It is a white, square-shaped surimi product with regional variants that can be fried, broiled, or eaten with soup.



Chikuwa: After the surimi is wrapped around a skewer, it is steamed or broiled to create chikuwa, a tube-shaped product with added salt, sugar, starch, and egg white. In Japan, chikuwa pieces that have been sliced from the cooked product are a common snack.



Fish balls: In Asia, fish balls are widely consumed and prepared in a variety of regional styles, sometimes using surimi.



References

- Hall, G. M. (2011) Surimi and Fish Mince Products. In Hall, G. M. (Ed.). Fish processing: sustainability and new opportunities. (pp. 98-111). John Wiley & Sons.
- Shitole, S. S., Balange, A. K. and Gangan, S. S. (2014). Use of seaweed (*Sargassum tenerrimum*) extract as gel enhancer for lesser sardine (*Sardinella brachiosoma*) surimi.

International Aquat. Research, 6(1): 55.

Yingchutrakul, M., Wasinnitiwong, N., Benjakul, S., Singh, A., Zheng, Y., Mubango, E., Luo, Y., Tan, Y. and Hong, H. (2022) Asian Carp, an Alternative Material for Surimi Production: Progress and Future. *Foods*, 11: 1318.

Climate Change and Aquaculture: Impacts and Sustainability Challenges

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Abstract

Climate change is increasingly recognized as a major global challenge affecting natural resources, food security, and livelihood systems. According to the Intergovernmental Panel on Climate Change (IPCC), global temperatures are projected to rise significantly by the end of the century, leading to increased frequency of extreme climatic events such as droughts, floods, and sea-level rise. Fisheries and aquaculture play a crucial role in providing high-quality animal protein, essential nutrients, and livelihood opportunities for millions of people worldwide, particularly in developing countries. The aquaculture systems are highly vulnerable to climate variability and environmental changes. Primary climate change indicators such as rising temperature, sea-level rise, altered rainfall patterns, and increased disease outbreaks can significantly influence fish growth, survival, water quality, and ecosystem productivity. Although certain opportunities, such as extended growing seasons and expansion of brackish water aquaculture, may arise, the overall impacts of climate change on aquaculture are predominantly negative, posing serious challenges to the sustainability and resilience of the sector.

Introduction

Climate change has emerged as one of the most critical global challenges affecting natural resources, agricultural production systems, and food security. According to the Intergovernmental Panel on Climate Change, global surface temperatures are projected to rise significantly during the 21st century, with warming likely to reach around 1.5°C above pre-industrial levels in the near future if current emission trends continue. Rising temperatures, altered precipitation patterns, sea-level rise, glacier retreat, and increased frequency of extreme weather events are widely recognized as major indicators of climate change. These changes are expected to influ-

ence agricultural productivity, water availability and ecosystem stability, posing serious challenges to global and regional food security (IPCC, 2022). In the context of developing countries such as India, climate change is expected to exacerbate environmental variability and increase the frequency of droughts, floods, and extreme climatic events. Such changes may significantly alter production environments and lead to substantial losses in agricultural productivity. Studies suggest that rising temperatures and changing rainfall patterns may reduce crop yields and affect rural livelihoods, thereby intensifying concerns related to food security and sustainable resource management (Porter *et al.*,

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2014). The impacts of climate change on fisheries and aquaculture are expected to be multifaceted and region-specific. In tropical and low-latitude regions, rising temperatures and increased climatic variability may lead to declining fish productivity, species migration, and localized extinctions. Furthermore, climate-induced changes in water quality, salinity intrusion, and the increased prevalence of diseases may negatively affect aquaculture production systems (FAO, 2022).

Importance of aquaculture

Aquaculture has emerged as one of the fastest-growing food production sectors in the world and plays a crucial role in ensuring global food and nutritional security. According to the Food and Agriculture Organization, aquaculture now contributes more than half of the aquatic animals consumed globally, surpassing capture fisheries in supplying fish for human consumption (FAO, 2022). With the increasing global population and stagnating capture fishery production, aquaculture provides a sustainable alternative to meet the rising demand for high-quality animal protein. Fish and other aquatic foods are rich sources of essential nutrients, including omega-3 fatty acids, vitamins and minerals, making aquaculture an important component of healthy diets worldwide (Fig. 1).

Aquaculture also plays a significant role in livelihood generation and poverty alleviation (Tanjay *et al.*, 2024), particularly in developing countries. The sector provides direct and indirect employment to millions of people through farming,

processing, marketing, feed production, and input supply chains. Small-scale fish farmers, especially in Asia and Africa, depend heavily on aquaculture as a source of income and household nutrition (Tacon and Metian, 2018). In countries like India, aquaculture has become an important driver of rural economic growth, contributing substantially to agricultural GDP and supporting the livelihoods of small and marginal farmers.

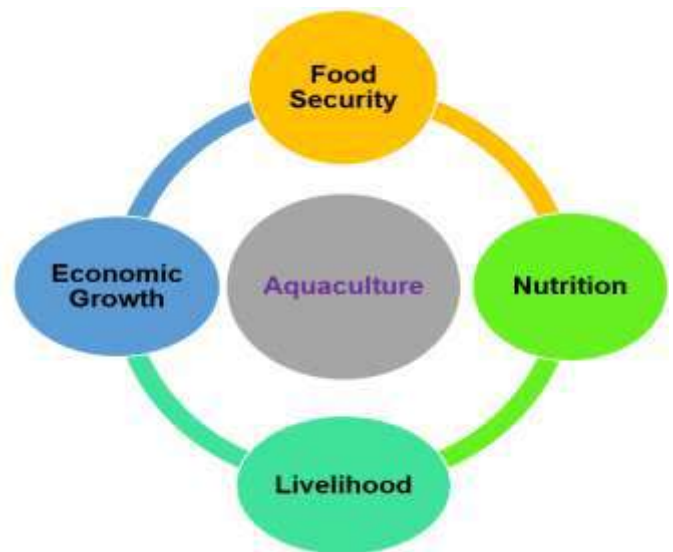


Fig. 1: Significance of aquaculture

In addition to economic benefits, aquaculture contributes to efficient resource utilization and the diversification of farming systems. Integrated aquaculture practices, such as fish-rice farming and aquaculture-livestock integration, enhance resource use efficiency and improve farm productivity. These systems allow farmers to maximize the use of land and water resources while reducing environmental impacts (Edwards, 2015). Furthermore, advances in aquaculture technologies, selective breeding, improved feeds, and better management practices have significantly increased production efficiency and

sustainability. Aquaculture is also increasingly recognized for its potential contribution to climate-resilient food systems. Compared with many terrestrial livestock systems, several aquaculture species have relatively lower feed conversion ratios and carbon footprints, making them a more sustainable source of animal protein (Hall *et al.*, 2011). As global demand for aquatic foods continues to rise, responsible and sustainable aquaculture development will remain essential for ensuring food security, supporting livelihoods, and promoting economic development in many parts of the world.

Climate change indicators

Climate change affects aquaculture through both direct and indirect pathways (De Silva and Soto, 2009). Direct impacts influence the physical environment and physiological processes of finfish and shellfish within aquaculture systems, while indirect effects occur through changes in ecosystem productivity, resource availability, and the supply and cost of essential inputs such as fishmeal and fish oil (Adhikari *et al.*, 2018). Although aquaculture has experienced substantial technological progress and expansion to meet the growing demand for aquatic products (FAO, 2022), climate change has emerged as a major challenge threatening the sustainability and resilience of aquaculture production systems worldwide. Several key indicators reflect the influence of climate change on aquaculture, including rising temperature, sea-level rise, changes in rainfall patterns, severe climatic events, and the emergence of diseases and harmful algal blooms (Fig

2). These indicators can alter water quality, species physiology, ecosystem dynamics and farm infrastructure, thereby affecting productivity, economic viability, and long-term sustainability of aquaculture systems.

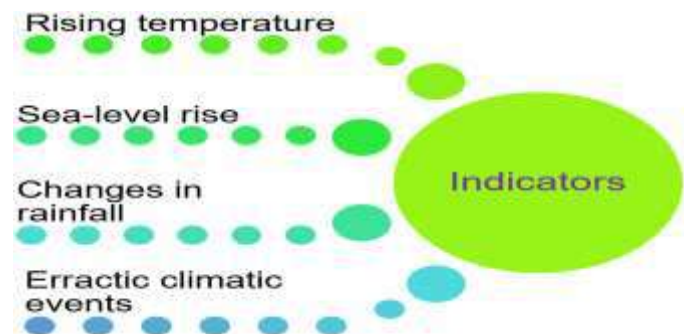


Fig. 2: Climatic indicators

Rising temperature: Temperature plays a crucial role in the growth and development of aquatic organisms. Fish are poikilothermic and therefore highly sensitive to temperature fluctuations caused by climate change. A projected rise of about 1.5°C in global temperature may increase mortality in several species, particularly cold-water fish such as salmon and cod, due to thermal stress (Ngoan, 2018). Prolonged temperature stress can negatively affect aquaculture productivity by disrupting physiological functions, including neuroendocrine and osmoregulatory systems, immune responses, metabolism, feeding behaviour, and growth performance of cultured species.

Sea level rise: Sea level rise is projected to continue throughout this century, largely depending on future greenhouse gas emission pathways (IPCC, 2022). Rising sea levels may damage coastal ecosystems such as mangroves and salt marshes, which are vital for maintaining fish stocks and providing seed resou-

resources for aquaculture. Saline water intrusion into freshwater systems can affect aquaculture infrastructure, including ponds and cages, leading to reduced productivity and increased production costs. Additionally, sea level rise may alter species distribution, abundance, and ecosystem productivity, thereby threatening aquaculture sustainability. However, in some coastal areas, it may also create opportunities for expanding brackish water aquaculture, particularly for high-value species such as shrimp and mud crab.

Changes in rainfall pattern: Variations in rainfall patterns influence aquaculture through both flooding and drought events. Increased rainfall and extreme precipitation can raise production risks in lowland aquaculture systems, causing fish loss, pond damage, and the introduction of invasive species, which may deteriorate water quality and environmental sustainability. Conversely, prolonged drought can lead to water shortages and declining water quality, negatively affecting aquaculture productivity. Climate-induced water scarcity may also intensify competition for water resources among aquaculture, agriculture, domestic, and industrial sectors, thereby threatening the overall sustainability of aquaculture production systems (Barange *et al.*, 2018).

Severe climatic events: Extreme climatic events such as cyclones, storms, waves, and storm surges pose significant risks to aquaculture, particularly in coastal regions. These events can damage aquaculture infrastructure, cause stock losses and increase production costs, especially in cage and coastal farm-

ing systems. Stronger storms may also lead to equipment failure and escape of cultured species, affecting the economic sustainability of aquaculture operations (Barange *et al.*, 2018). Although severe storms generally have negative impacts, they may occasionally contribute to nutrient mixing and reduction of water temperature, which can help improve water quality and ecosystem productivity in some cases (Toussaint *et al.*, 2018).

Diseases and harmful algal blooms: Climate change can significantly influence the occurrence and spread of diseases in aquaculture. Rising temperatures and thermal stress increase the susceptibility of cultured finfish and shellfish to bacterial, viral, parasitic, and fungal infections. Warmer conditions may enhance pathogen replication, virulence, and transmission, leading to more frequent disease outbreaks and the possible emergence of new or exotic pathogens. In addition, both direct and indirect thermal stressors affect host-pathogen interactions, increasing the vulnerability of aquatic species. Consequently, disease outbreaks and harmful algal blooms have become major constraints to aquaculture productivity and sustainability worldwide (Maulu *et al.*, 2019).

Impact of climate change on aquaculture

Climate change has emerged as a significant driver influencing aquaculture production systems worldwide. Various climatic elements such as rising temperature, altered rainfall patterns, sea-level rise, disease dynamics, and changes in salinity can affect aquatic ecosystems and cultured species in multiple

ways. These environmental changes often disrupt water quality, species physiology, and ecosystem stability, thereby influencing the productivity and sustainability of aquaculture operations (Chauhan *et al.*, 2026). In most cases, the impacts of climate change on aquaculture are predominantly negative, leading to reduced growth and survival of cultured species, increased disease outbreaks, deterioration of water quality and damage to aquaculture infrastructure. These challenges often result in higher production costs and greater uncertainty for aquaculture farmers. However, some potential positive effects may occasionally arise, such as extended growing seasons for warm-water species, opportunities for genetic improvement, expansion of brackish water aquaculture areas (Fig. 3).

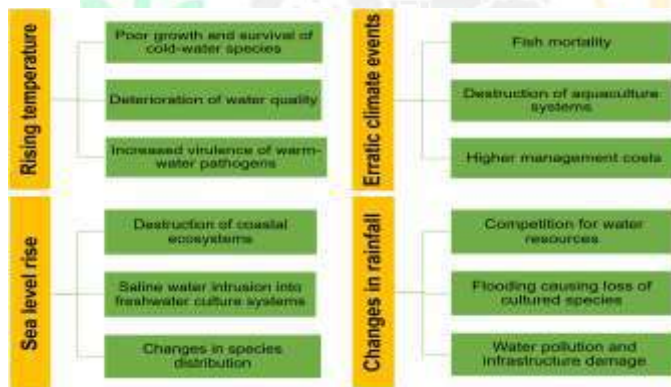


Fig. 3: Impact of climate change on aquaculture

Conclusion

Climate change poses significant challenges to aquaculture by altering environmental conditions such as temperature, rainfall patterns, sea level, and the occurrence of extreme climatic events. These changes can negatively affect water quality, species growth, disease dynamics and aquaculture infrastructure, ultimately reduce productivity and increase

production risks. Although certain opportunities may arise, such as the expansion of brackish water aquaculture and the development of climate-resilient species, the overall impacts are likely to be predominantly negative. Therefore, strengthening climate-resilient aquaculture practices, improving management strategies, and promoting technological innovations are essential to ensure the sustainability and long-term productivity of the aquaculture sector.

References

- Adhikari, S., Keshav, C. A., Barlaya, G., Rathod, R., Mandal, R. N, Ikmail, S., *et al.* (2018). Adaptation and mitigation strategies of climate change impact in freshwater aquaculture in some states of India. *Journal of Fish*, 12: 016-021.
- Barange, M., Bahri, T., Beveridge, M. C. M., Cochrane, A. L., Funge-Smith, S. and Paulain, F. (2018). Impacts of Climate Change on Fisheries and Aquaculture, Synthesis of Current Knowledge, Adaptation and Mitigation Options. Rome: FAO.
- Chauhan, S., Chauhan, J. K., Upadhyay, A. D., Chandegara, A. K. and Tanjay, T. (2026). Community-based adaptation and mitigation in Indian fisheries under climate change: A Systematic Literature Review (SLR). *Indian Research Journal of Extension Education*, 26 (2): 141-150
- Edwards, P. (2015). Aquaculture environment interactions: Past, present, and likely future trends. *Aquaculture*, 447: 2-14.

- De Silva, S. S. and Soto, D. (2009). Climate change and aquaculture: potential impacts, adaptation and mitigation. in *Climate Change Implications for Fisheries and Aquaculture: Overview of Current Scientific Knowledge*. FAO Fisheries and Aquaculture Technical Paper. No. 530, Eds K. Cochrane, C. De Young, D. Soto, and T. Bahri (Rome: FAO), 151-212.
- FAO. (2022). *The State of World Fisheries and Aquaculture 2022: Towards blue transformation*. Rome: Food and Agriculture Organization.
- Hall, S. J., Delaporte, A., Phillips, M. J., Beveridge, M. and O'Keefe, M. (2011). *Blue frontiers: Managing the environmental costs of aquaculture*. Washington, DC: The WorldFish Center and the World Bank.
- IPCC. (2022). *Climate change 2022: Impacts, adaptation and vulnerability*. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press.
- Maulu, S., Munganga, B. P., Hasimuna, O. J., Haambiya, L. H. and Seemani, B. (2019). A review of the science and technology developments in Zambia's aquaculture industry. *Journal of Aquaculture Research and Development*, 10: 567.
- Ngoan, L. D. (2018). Effects of climate change in aquaculture: case study in Thua Thien Hue Province, Vietnam. *Biomed. Journal of Science and Technology Research*, 10: 2018.
- Porter, J. R., Xie, L., Challinor, A. J., Cochrane, K., Howden, S. M., Iqbal, M. M., ... and Travasso, M. I. (2014). Food security and food production systems. In *Climate change 2014: Impacts, adaptation, and vulnerability* (pp. 485-533). Cambridge University Press.
- Tacon, A. G. J. and Metian, M. (2018). Global overview on the use of fish meal and fish oil in aquafeeds. *Aquaculture*, 285(1-4): 146-158.
- Tanjay, T., Chauhan, J. K., Upadhyay, A. D., Lahiri, B., Pal, P., Chandegara, A. K. and Chauhan, S. (2024). Group dynamics effectiveness of fishery based self-help groups in Tripura. *Indian Research Journal of Extension Education*, 24(4): 129-136.
- Toussaint, M., Gyalog, G., Hough, C. and Ytteborg, E. (2018). *The Effects of Climate Change upon Aquaculture*. Oslo: Climefish.

Advances in Precision Feeding Systems for Dairy Cattle

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Abstract

Precision feeding systems for dairy cattle integrate sensor technologies, automated feeding hardware, nutritional modeling, and data analytics to optimize nutrient delivery at the individual animal level. These systems aim to improve feed efficiency, enhance milk production, reduce metabolic disorders, and minimize environmental nutrient losses. This article reviews recent technological advances, system architectures, algorithmic approaches, performance outcomes, and implementation challenges associated with precision feeding in modern dairy operations.

Introduction

Feed represents 50-60% of total dairy production costs. Traditional feeding systems typically provide group based total mixed rations (TMR) formulated to meet the average requirements of a production group. However, within group variability in milk yield, body weight, parity, and health status leads to nutrient over or under supply at the individual level. Precision feeding systems address this inefficiency by dynamically adjusting nutrient supply according to individual animal requirements using real time data streams and automated feed delivery mechanisms.

System Architecture of Precision Feeding Platforms

Modern precision feeding systems consist of

four integrated layers:

Data Acquisition Layer

- ✓ RFID based individual identification
- ✓ Automated feed intake measurement systems
- ✓ Milk yield and milk component sensors
- ✓ Body weight scales (walk over systems)
- ✓ Rumination and activity monitoring collars
- ✓ Environmental sensors (temperature humidity index).

These devices generate high frequency longitudinal datasets for each cow.

Data Processing and Integration Layer

Collected data are transmitted to centralized farm management software or cloud based platforms

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where:

- ✓ Intake and performance data are cleaned and validated
- ✓ Nutritional requirement models are applied
- ✓ Deviations from expected performance curves are calculated. APIs increasingly enable interoperability between milking systems, feeding robots, and herd management software.

Decision Support Algorithms

Advanced systems incorporate

- ✓ Mechanistic nutritional models (e.g., energy and protein requirement equations).
- ✓ Predictive regression models for milk yield forecasting.
- ✓ Machine learning algorithms for anomaly detection.
- ✓ Reinforcement learning for feed optimization over time

Algorithms adjust concentrate allocation, protein supplementation, or energy density based on real time production metrics.

Feed Delivery and Execution

Layer Implementation mechanisms include

- ✓ Automated concentrate feeders linked to individual ID
- ✓ Robotic feed pushers to maintain feed accessibility
- ✓ Intelligent TMR batching systems with precision ingredient dosing
- ✓ Multi component feeding stations enabling differential supplementation

Nutritional Optimization Strategies

Precision feeding enables several advanced strategies

Individualized Concentrate Allocation

Cows receive variable concentrate levels proportional to

- ✓ Current milk yield
- ✓ Lactation stage
- ✓ Body condition score
- ✓ Parity

This reduces overfeeding in low producing animals and supports high producing individuals more effectively.

Dynamic Protein and Amino Acid Balancing:

Real time milk urea nitrogen (MUN) and milk protein data allow adjustment of rumen degradable protein (RDP) and rumen undegradable protein (RUP) fractions. Targeted amino acid supplementation (e.g., lysine, methionine) improves nitrogen use efficiency.

Phase Feeding: Across Lactation Automated systems allow frequent transitions between dietary phases, reducing abrupt nutritional shifts that can predispose cows to metabolic stress.

Health Monitoring and Risk Prediction: Feeding behavior metrics (meal frequency, duration, intake rate, rumination time) are strongly correlated with metabolic health. Precision systems can detect early indicators of:

- ✓ Subclinical ketosis
- ✓ Ruminal acidosis
- ✓ Lameness
- ✓ Heat stress

Machine learning models trained on historical

datasets identify deviations from normal intake patterns 24-72 hours before clinical diagnosis, enabling preventive intervention.

Environmental and Sustainability Impacts

Precision feeding contributes to environmental sustainability by:

- ✓ Reducing nitrogen excretion via improved protein efficiency.
- ✓ Lowering phosphorus oversupply.
- ✓ Improving feed conversion efficiency (kg milk/kg DMI)
- ✓ Reducing methane intensity per unit of milk

Dynamic ration adjustment based on forage analysis and real time performance reduces nutrient waste and feed import dependency.

Performance Outcomes

Research trials and commercial farm data report

- ✓ 2-8% improvement in feed efficiency
- ✓ Reduced feed cost per kg of milk
- ✓ Lower within herd variation in body condition
- ✓ Reduced incidence of metabolic disorders in early lactation
- ✓ Return on investment depends on herd size, milk price, feed costs, and degree of system automation.

Implementation Challenges

Capital Investment: High initial costs for sensors, automated feeders, and software platforms may limit adoption.

Data Integration: Incompatibility between proprietary systems can hinder full scale integration.

Data Quality and Calibration: Sensor drift, miss-

ing data and improper calibration can compromise model accuracy.

Skill Requirements: Effective use requires training in data interpretation and system maintenance.

Future Directions

Emerging developments include

- ✓ Integration of genomic and metabolomic data into nutritional models
- ✓ Real time rumen fermentation monitoring via bolus sensors
- ✓ AI driven autonomous ration formulation
- ✓ Whole farm optimization models integrating feeding, reproduction, and health

The long term trajectory suggests increasing automation combined with predictive analytics to enhance biological efficiency and sustainability.

Conclusion

Precision feeding systems represent a significant advancement in dairy production technology. By integrating real time animal data, predictive modeling, and automated feed delivery, these systems improve nutrient utilization efficiency, animal health monitoring, and environmental stewardship. While economic and technical barriers remain, ongoing innovation is expected to further enhance scalability and system robustness.

From Self-Sufficiency to Sustainability: Minimizing Post-Harvest Losses in Agriculture and Horticulture

Prakash Sonnad, Sandeep, Sahana K. R. and Ranjitha S. M.

Abstract

Despite unprecedented agricultural abundance, with India yielding approximately 357.7 million tonnes of food grains and 367.7 million tonnes of horticultural crops in 2024-25, systemic post-harvest leakages severely undermine national food security. The country faces an estimated annual economic loss of Rs.1.53 trillion. Horticultural spoilage reaches 10% to 15%, while durable grain losses average 4.6% to 6%. This article advocates for an urgent paradigm shift from quantitative “self-sufficiency” to a qualitative commitment to “sustainability”. Mitigating these deficits requires addressing distinct biological bottlenecks. Durable grains are primarily threatened by abiotic and biotic factors, including moisture migration, storage fungi, and insect pests. Conversely, fresh produce suffers from rapid physiological deterioration driven by high respiration rates and enzymatic spoilage. These vulnerabilities are exacerbated by infrastructural gaps, specifically the absence of an unbroken farm-gate cold chain and a chronic shortage of decentralized, scientific storage. Traditional methods, like rudimentary godowns and Cover and Plinth (CAP) storage, offer inadequate protection and force distress selling. A comprehensive technological and policy overhaul is essential. Macro-level interventions must include transitioning to climate-controlled steel silos, IoT-integrated “Smart Godowns” for real-time monitoring, and GIS spatial planning to optimize supply chains. Grassroots empowerment is equally critical. Promoting accessible innovations like hermetic storage bags and Zero Energy Cool Chambers (ZECCs) provides immediate relief. Leveraging Farmer Producer Organizations (FPOs) backed by the Agriculture Infrastructure Fund (AIF) builds vital village-level capacities. Minimizing post-harvest waste remains a critical imperative for agricultural prosperity.

Introduction: The Paradox of India’s Bumper Harvests

Indian agriculture is currently witnessing an era of unprecedented abundance, marking a triumph-

ant milestone in our agronomic journey. According to the Economic Survey 2025-26, India achieved a historic record in food grain production, reaching approximately 357.7 million tonnes in the 2024-25

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crop year (Ministry of Finance, 2026). This monumental harvest, driven by robust yields in rice, wheat and coarse cereals, is paralleled by exceptional achievements in the horticultural sector, which soared to an estimated 367.7 million tonnes in the same period, surpassing food grain production and highlighting a gradual diversification towards high-value crops (Ministry of Finance, 2026). This continuous upward trajectory reflects the resilience of our cropping systems and the success of modern agricultural practices. However, this quantitative triumph conceals a pressing qualitative paradox. While our fields consistently yield bumper crops, our supply chains struggle to preserve them, leading to a stark disconnect between what is harvested and what actually secures national nutrition.



Fig. 1. Bountiful Harvest Compared with Spoilage and Pest-Infested Grain in Traditional Storage

Producing enough food means little if we lack the infrastructure to store it safely. The harsh reality of the current agricultural landscape is the staggering volume of post-harvest loss that occurs between the farm gate and the retail market. A comprehensive nationwide study by NABARD Consultancy Services (NABCONS) revealed that

India suffers an estimated post-harvest economic loss of Rs.1.53 trillion annually (NABCONS, 2022). For horticultural produce specifically, post-harvest losses range from 10% to 15%, amounting to 10 million tonnes of wasted fruits and vegetables each year (ICAR-CIPHET, 2015; Ministry of Food Processing Industries, 2022). Similarly, durable food grains experience substantial losses by weight averaging between 4.6% and 6% often facing severe qualitative depreciation before reaching consumers (NABCONS, 2022). These post-harvest deficits do more than undermine food security and inflate consumer prices; they represent a colossal, irrecoverable waste of the water, fertilizers, and intensive labour invested during cultivation. To secure the future of our agricultural economy, we must urgently pivot our national focus. The era of merely chasing higher production numbers is behind us; the time has come to shift our paradigm from a quantitative goal of “self-sufficiency” to a qualitative, long-term commitment to “sustainability.” Eliminating post-harvest waste is the definitive cornerstone of this transition. By modernizing our storage facilities through the integration of real-time monitoring systems and optimizing rural supply chains, we can effectively safeguard our surplus. Transforming our traditional godowns into active, tech-enabled environments ensures that every grain and vegetable harvested translates into actual economic value. This strategic evolution will not only maximize profitability at the grassroots level but also fortify the nation against future vulnerabili-

es, proving that true agricultural resilience is measured not just by what we grow, but by what we successfully preserve.

Understanding the Bottlenecks: Grains vs.

Perishables: To effectively mitigate post-harvest losses, it is crucial to recognize that the storage ecosystems for durable food grains and perishable horticultural crops are fundamentally distinct. Each category is governed by its own unique set of biological and environmental bottlenecks, requiring highly specific management strategies. For food grains such as cereals and pulses, the primary drivers of deterioration are a complex interplay of abiotic and biotic factors. Food grains are highly hygroscopic, meaning they constantly absorb and release moisture based on the relative humidity of their surrounding environment. While the safe moisture content for storing most cereals is generally below 10% to 12%, traditional Indian storage infrastructure often fails to maintain this critical threshold (Nath *et al.*, 2024). Poor ventilation, floor seepage, and the unscientific, dense stacking of gunny bags restrict airflow, leading to moisture migration and the formation of localized “hot spots” within the grain bulk. This abiotic stress immediately triggers devastating biotic consequences. Elevated moisture and temperature create an ideal micro-climate for opportunistic storage fungi, particularly ubiquitous species of *Aspergillus* and *Penicillium*. These fungal pathogens not only cause dry matter loss but also synthesize hazardous mycotoxins, which severely compromise health. Furthermore,

these compromised storage environments act as breeding grounds for insect pests. In many developing regions, insect pests alone can cause up to 30% of the total grain losses during storage if left unchecked (Kumar and Kalita, 2017; Berhe *et al.*, 2022).

In stark contrast, the post-harvest bottlenecks for horticultural crops stem primarily from their inherent physiological composition. Unlike dormant, dry grains, fresh produce consists of highly active, living tissues with an exceptionally high moisture content, typically ranging between 80% and 95%. The most critical post-harvest challenge for these crops is managing their respiration rate. Even after harvest, fruits and vegetables continue to “breathe,” consuming their own stored carbohydrates while releasing metabolic heat. In the absence of immediate temperature control, elevated ambient temperatures drastically accelerate this respiration, leading to rapid senescence and severe shrivelling (Singh *et al.*, 2024). Compounding this is rapid enzymatic spoilage. Intrinsic enzymes remain highly active post-harvest, triggering rapid tissue softening, which makes the high-moisture tissue highly susceptible to secondary invasions by soft-rot bacteria. Therefore, while grain storage focuses on maintaining a dry, pest-free environment over several months, the bottleneck for perishables is a highly time-sensitive race. The lack of immediate pre-cooling facilities at the farm gate ensures that irreversible deterioration often begins within hours of harvest.

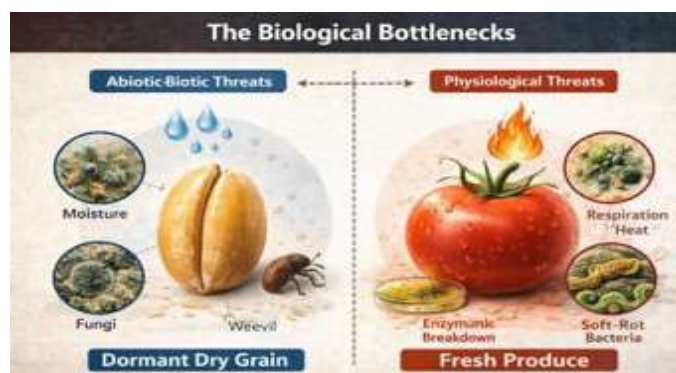


Fig. 2 The Biological Bottlenecks: Distinct post-harvest deterioration pathways in dry grains and fresh produce.

Infrastructure Deficits: Where Does the Leakage Occur?

Identifying the exact nodes where leakage occurs within the agricultural supply chain is essential for deploying targeted interventions. In the Indian context, the journey of agricultural produce from the farm gate to the consumer plate is fraught with infrastructural deficits that systematically degrade crop quality and quantity. The first major point of leakage occurs immediately during and after the harvest. Due to a heavy reliance on manual harvesting or improperly calibrated mechanical harvesters, grains frequently suffer from mechanical damage, such as cracking or bruising, which immediately predisposes them to insect attack during storage (Gulati *et al.*, 2024). For horticultural crops, rough handling during plucking, sorting and grading leads to epidermal abrasions. Because grading is often done directly on the soil or unpaved farm floors, fresh produce is instantly exposed to soil-borne pathogens. Following the harvest, the transit from the farm gate to the local mandi (wholesale market) constitutes a critical vulnerability. Produce

is typically transported in unspecialized, open-bed vehicles (such as tractor-trolleys) under the scorching sun. The lack of reefer (refrigerated) vehicles means that the vital “cold chain” which should ideally begin the moment a fruit or vegetable is harvested is completely absent. This thermal shock accelerates respiration and moisture loss before the produce even reaches the market (Singh *et al.*, 2024).

The most severe infrastructural deficit, however, is the chronic shortage of decentralized, scientific storage at the village level. Indian agriculture relies heavily on distant, centralized warehousing. For farmers, transporting bulk produce to these distant facilities is often economically unviable due to high freight costs and the risk of transit damage. Consequently, a vast majority of small and marginal farmers are forced into “distress selling” during the harvest season when market gluts drive prices to their lowest (Gulati *et al.*, 2024).

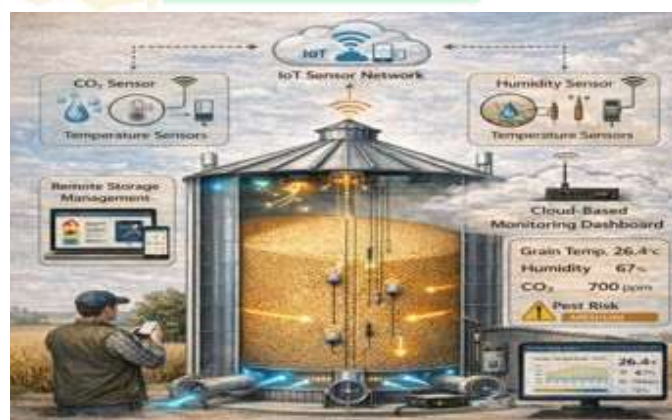


Fig. 3: The Smart Godown: Digital Intelligence for Modern Grain Storage

Those who attempt to store their produce locally often resort to traditional structures like mud bins or rudimentary godowns that offer zero protection against rodents, moisture ingress or temperature

fluctuations. Even at the institutional level, the prolonged use of Cover and Plinth (CAP) storage where grain bags are stacked in the open and covered with polyethylene sheets exposes millions of tonnes of wheat and paddy to extreme weather aberrations, bird damage, and ground moisture, leading to significant qualitative downgrades (NABCONS, 2022).

Tech-Driven Interventions: Smart Godowns and Cold Chains

Transitioning from self-sufficiency to sustainability requires a complete technological overhaul of how we perceive and manage agricultural storage. The traditional godown must evolve from a passive holding area into an active, tech-driven environment. Modernizing post-harvest management heavily relies on the integration of smart technologies, spatial planning, and robust cold chains. For durable commodities, the shift from traditional bag-storage to modern, climate-controlled steel silos is paramount. Steel silos offer hermetic sealing, automated aeration, and precise temperature control, drastically reducing the reliance on chemical fumigants. However, the true revolution in storage lies in the application of the Internet of Things (IoT). “Smart Godowns” equipped with IoT sensor networks can continuously monitor the microclimate specifically inter-granular temperature, relative humidity, and CO₂ concentrations in real-time. For high-value, semi-perishable crops like onions, which require highly specific curing and ventilation regimes to prevent rotting and sprouting, IoT-

enabled real-time monitoring is transformative. Sensors can instantly detect a spike in CO₂ or temperature (indicating fungal respiration or insect hotspots) and automatically trigger exhaust fans or send immediate alerts to facility managers, allowing for proactive intervention before a localized issue spoils the entire bulk (Guru *et al.*, 2022; Nath *et al.*, 2024).

Equally important is the macro-level management of storage infrastructure using Geographic Information Systems (GIS). GIS spatial planning is a powerful agronomic tool that can map out existing production clusters, track the capacity of surrounding warehouses, and optimize supply chain routes. By analysing spatial data on crop yields, road connectivity, and regional climate risks, policymakers can pinpoint the exact geographic locations where new cold storage or smart godowns are desperately needed, thereby reducing the transit time from farm to facility. For highly perishable horticultural crops, establishing an unbroken, tech-enabled cold chain is non-negotiable. This involves establishing pack-houses equipped with forced-air pre-cooling systems right at the farm gate, ensuring the field heat is removed immediately. When combined with reefer transport and GIS-tracked logistics, the shelf life of Indian fruits and vegetables can be extended by weeks, drastically curbing the 15% spoilage rate currently plaguing the sector (ICAR-CIPHET, 2015).

Empowering the Grassroots: Policy and Farmer Interventions

While high-tech silos and IoT-integrated godowns are the future, sustainability cannot be achieved without empowering the grassroots level. The majority of Indian agriculture is driven by smallholder farmers who require accessible, low-cost interventions and robust policy support to mitigate localized post-harvest losses. At the farm level, promoting low-cost, scientifically validated storage technologies is crucial. For grains and pulses, the widespread adoption of hermetic storage bags which restrict oxygen and moisture exchange, naturally suffocating stored-grain insects without the use of toxic pesticides has proven highly effective and affordable for rural households (Kumar and Kalita, 2017). For horticultural farmers, the establishment of Zero Energy Cool Chambers (ZECC) offers a practical, off-grid solution. Constructed from locally available bricks and sand, ZECCs utilize the principle of evaporative cooling to maintain internal temperatures significantly lower than the ambient environment, effectively doubling the short-term shelf life of fresh vegetables and allowing farmers to bypass immediate distress sales.



Fig. 4: Zero Energy, Maximum Freshness: A smallholder farmer using a low-cost ZECC to beat the heat and save the harvest

Institutionally, the aggregation of farmers into Farmer Producer Organizations (FPOs) is a game-changer for post-harvest management. Individual smallholders lack the capital to build scientific storage, but an FPO can pool resources to establish decentralized, village-level warehouses, primary processing units, and custom hiring centres for mechanical dryers. The Government of India has recognized this necessity and introduced pivotal policy interventions. The Agriculture Infrastructure Fund (AIF), launched with a massive financial outlay, is specifically designed to provide medium-to-long-term debt financing facilities for investment in viable post-harvest management infrastructure and community farming assets (Department of Agriculture & Farmers Welfare, 2025). By heavily subsidizing the interest rates for FPOs and Agri-entrepreneurs to build cold storages, assaying units, and smart godowns at the village level, the AIF is directly addressing the core infrastructural deficits. Furthermore, linking these rural warehouses to the electronic National Agriculture Market (e-NAM) through electronic Negotiable Warehouse Receipts (e-NWRs) allows farmers to store their produce safely and access institutional credit against it, completely altering their market bargaining power.

Conclusion: A Sustainable Roadmap Forward

The narrative of Indian agriculture has been defined by our remarkable ability to overcome production deficits and achieve national food security. Yet, as the Economic Survey 2025-26 highlights, while our crop yields and horticultural

outputs continue to break global records, our true agronomic potential remains constrained by systemic post-harvest leakages. A grain saved from spoilage is, in every economic and environmental sense, a grain produced. Moving forward, minimizing post-harvest losses must be viewed not just as an economic necessity, but as a critical environmental imperative. The millions of tonnes of food lost annually represent a massive squandering of India's precious groundwater, soil nutrients, and agricultural labour. To build a truly sustainable roadmap, we must aggressively bridge the gap between traditional farming and modern logistics. This requires a multi-pronged approach: transitioning from CAP storage to tech-enabled smart godowns, leveraging IoT and GIS for real-time monitoring and spatial planning, and aggressively expanding the farm-gate cold chain. Simultaneously, we must empower our grassroots farmers through FPOs and government financing to ensure that these advanced infrastructural capacities reach the village level. By scientifically securing our surplus, we can ensure that the fruits of our farmers' labour are fully realized, transforming our agricultural abundance into lasting, sustainable prosperity for the nation.

References

- Berhe, M., Subramanyam, B., Chichaybelu, M., Demissie, G., Abay, F. and Harvey, J. (2022). Post-Harvest insect pests and their management practices for major food and export crops in East Africa: An Ethiopian case study. *Insects*, 13(11): 1068.
- Department of Agriculture & Farmers Welfare. (2025). Annual report 2024-25. Ministry of Agriculture & Farmers Welfare, Government of India.
- Gulati, A., Sharma, P. and Singh, S. (2024). Reducing post-harvest losses in Indian agriculture: A case study of selected crops. Indian Council for Research on International Economic Relations (ICRIER).
- Guru, P. N., Mridula, D., Dukare, A. S., Ghodki, B. M., Paschapur, A. U., *et al.* (2022). A comprehensive review on advances in storage pest management: Current scenario and future prospects. *Frontiers in Sustainable Food Systems*, 6.
- ICAR-Central Institute of Post-Harvest Engineering and Technology (CIPHET). (2015). Assessment of quantitative harvest and post-harvest losses of major crops and commodities in India. Indian Council of Agricultural Research.
- Kumar, D. and Kalita, P. (2017). Reducing post-harvest losses during storage of grain crops to strengthen food security in developing countries. *Foods*, 6(1): 8.
- Ministry of Finance. (2026). Economic survey 2025-26. Government of India.
- NABARD Consultancy Services (NABCONS). (2022). Study to determine post-harvest losses of agri produces in India. Ministry of Food Processing Industries, Government of India.

Ministry of Food Processing Industries. (2022). Post harvest food loss. Press Information Bureau, Government of India.

Nath, B., Chen, G., O'Sullivan, C. M. and Zare, D. (2024). Research and technologies to reduce grain postharvest losses: A review. *Foods*, 13(12): 1875.

Singh, S., Sharma, S., Panwar, S., Krishna, H., Singh, S. K., *et al.* (2024). Post-harvest management and value addition in vegetable crops. *Vegetable Science*, 51: 34-42.



Weather Impact on Mango and Management Strategy: An Overview

Surabhi Sharma and Vijay Kumar

Abstract

Studies have reported that adverse weather conditions most rottenly results into significant yield losses (20% to over 50%) in key mango production areas of India. The temperature extremes, heat stress, dry spells, heavy rains, hails etc. abiotic factors significantly disrupt physiological, reproductive, and developmental processes thereby adversely affecting flowering time, flower bud differentiation, pollination, fruit set, yield and fruit quality in mango. Thus it is essential to follow effective management strategies to mitigate different abiotic stresses in mango production.

Introduction

Mango (*Mangifera indica* L.) the king of fruit is a popular commercially fruit crop. India is the world's largest producer of mango accounting for 54% of global mango production. Mango is cultivated approximately in 6 million hectares area, predominantly in tropical and subtropical regions of the world (Laxman *et al.*, 2016). In tropical and subtropical climate, mango thrives in areas from sea level up to 1,500 meters receiving 250 mm to 2500 mm of annual rainfall. Mangoes grow best in climates which have low rainfall and low relative humidity at flowering, fruit setting and harvesting, and that are warm to hot during fruiting.

Climate and Weather: Climate and weather play an important role in growth and productivity of mango. Yield losses in mango under different agro-climatic conditions vary from region to region. Adverse weather parameters i.e. unseasonal rainfall, tempera-

ture fluctuations, dry spells, high winds etc have caused significant yield losses (20% to over 50%) in key mango production areas of India in recent years. These abiotic factors disrupt the physiological, reproductive and developmental processes, in mango and adversely affect the flowering time, flower bud differentiation, pollination, fruit set, yield and fruit quality (Manzoor *et al.*, 2023).

Temperature: Temperature is one of the main environmental factors that affects the flowering phenomenon in the majority of fruit crops, including mango crops. The favorable temperature for growth and development of mango ranges from 18 to 35 °C. In sub-tropics, cool weather at 15 degree Celsius temperatures or lower favors flower morphogenesis (flower bud induction) whereas higher temperatures of about 20°C initiates vegetative morphogenesis i.e vegetative shoots (Nunez-Elisea and Davenport, 1994). The rising temperatures cause earliness in

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flowering, disruption in bud break and pollination and shortening in flowering phase besides inducing the incidence of physiological disorder such as blackening of the mango tip. High temperatures (above 35-40°C) during fruit development trigger the production of abscisic acid leading to premature fruit drop. Moreover when night temperatures exceed 17°C during flower induction period (December-January), trees often produce vegetative flushes instead of flowers. Cool temperatures are mandatory for floral initiation, synchronized bloom, fruit set, and extended flowering and fruit development periods. Besides lower temperatures, water stress is pre-requisite for flower buds induction at the stage of flower morphogenesis. This phenomenon of floral induction and inhibition takes place irrespective of short and long photoperiod. Kumar *et al.* (2014) noted that temperature variations were more critical than photoperiods. Growth is totally halted when temperatures drop below 15 °C. Low temperatures have a negative impact on the process of pollen tube germination and growth. Low temperatures (e.g., 20/10°C day/night) during flowering can cause morphological changes like shorter styles, smaller stigmas, and embryo abortion, which drastically reduce fruit set. Low temperature stress also manifests increased oxidative damage in plants.

Heat Stress: Early- to mid-season cultivars in North India may be affected badly by severe heat coinciding with critical maturity stages. Heat stress can reduce sugar accumulation in fruits. In heat-

sensitive mango cultivars such as Dashehari, exposure to elevated temperatures results in internal tissue breakdown, while in 'Alphonso', it manifests as spongy tissue formation, where enzymes fail to ripen the flesh properly and both the disorders render the fruits unfit for consumption (Dwivedi *et al.*, 2024). The extreme heat waves with temperatures reaching 41-47 °C over 25 days, may have significant impacts on sensitive cultivars. The stored starch in heat-wave-affected fruits does not convert into simple sugars. In contrast, in case of heat wave-tolerant genotypes and hybrids, complex sugars are naturally broken down into simple sugars during ripening. Therefore, a lower sucrose level is observed in heat-tolerant mango genotypes and hybrids (Zhou *et al.*, 2015).

Rainfall: Major impact on mango production is revealed due to unseasonal rains at the time of flowering from November to March which adversely affect the activities of pollinators and moreover the pollens are washed away and it away causes poor fruit set and incidence of insect-pest and diseases like anthracnose and powdery mildew. Additionally, continuous rainfall induces physiological disorders by increasing soil moisture to the extent that key nutrients especially calcium and potassium are leached away. Thus, heavy rainfall initiates pollination failure, fruit cracking, pathogen invasion, reduced ripening and nutrient loss which together contribute to a measurable decline in mango yield and quality. Heavy rains near maturity can cause fruit splitting and increase the risk of post-harvest decay

and diseases like stem-end rot.

Wind: Wind speed has significant positive and negative effects on mango crop physiology. The process of pollination, transpiration and photosynthesis and air circulation are favored due to moderate winds and strong winds damages the trees and causes fruit drop, fruit scarring and excessive transpiration, cuticular loss and water loss. Increasing wind up to a point benefits plants physiologically by enhancing stomatal CO₂ uptake and photosynthesis through turbulence and altering hormone dynamics like ethylene and gibberellins.

Soil-plant-atmosphere continuum: Weather parameters like temperatures, humidity, rainfall, sunshine hours, light intensity and wind speeds during different phenophases of crop significantly affect the yield and quality of mango directly or indirectly through manipulation of micro climate. Evaporation rate is the most critical parameter in developing soil-plant-atmosphere continuum in favor of nutrient and water translocation and prevention of heat stress. The variations in micro-climate may occur due to factors such as wind patterns, soil moisture gradients and shade experienced by individual trees. In general, the results revealed that flower intensity and fruit growth was positively correlated with temperature, sunshine hours and evaporation due to enhanced photosynthesis while humidity showed a negative correlation.

Strategy: The effective management practices such as planting of climate-resilient varieties, fertigation

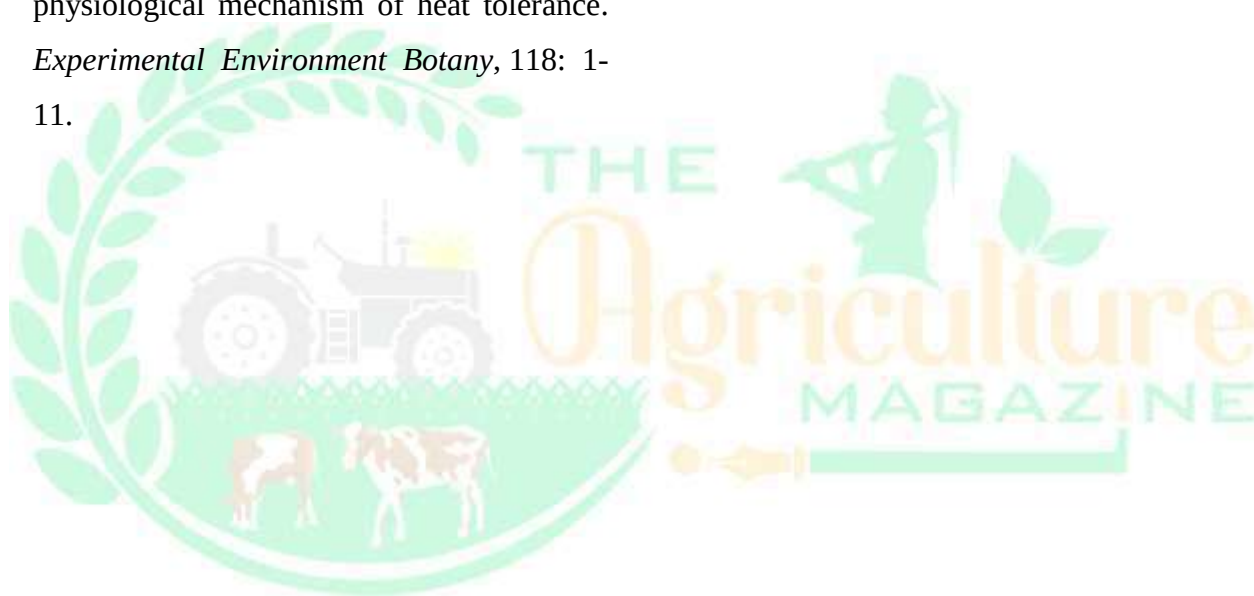
and drip irrigation, use of windbreaks and shelter belts, fruit bagging, foliar spray of nutrients and plant growth regulators, use of organic mulch or plastic films, open centre pruning, protective netting etc. should be followed to mitigate different abiotic stresses in mango production. Late maturing cultivar Amrapali and hybrids have exhibited tolerance by avoiding peak heat periods. Pusa Pratibha and Pusa Shrestha are more tolerant to high temperatures during fruit development. Kesar is reported for resilience to fluctuating humidity compared to Alphonso.

References

- Dwivedi, S. K., Mishra, D., Gupta, A. K., Dayal, V., Kumar, D., Singh, S. K.; Saroj, P. L. and Soni, S. K. (2024). Jelly seed disorder in mango: A comprehensive review of current status and future directions. *Applied Fruit Science*, 66: 1659-1668.
- Kumar, M., Ponnuswami, V., Kumar, P. J. and Saraswathy, S. (2014). Influence of season affecting flowering and physiological parameters in mango. *Science Research Essays*, 9(1): 1-6.
- Laxman, R. H., Annapoornamma, C. J. and Biradar, G. (2016). Mango. In *Abiotic Stress Physiology of Horticultural Crops*; Springer: Berlin/Heidelberg, Germany, pp. 169-181.
- Nunez-Elisea, R. and Devenport, T. L. (1994). Flowering of mango trees in containers as influenced by seasonal temperature and water stress. *Scientia Hort.*, 58: 57-66.

Manzoor, M. A., Xu, Y., Xu, J., Wang, Y., Sun, W., Liu, X., Wang, L., Wang, J., Liu, R. and Whiting, M. D. (2023). Fruit crop abiotic stress management: A comprehensive review of plant hormone-mediated responses. *Fruit Research*, 3: 1-18.

Zhou, R., Yu, X., Kjær, K. H., Rosenqvist, E. and Ottosen, C. O. (2015). Screening and validation of tomato genotypes under heat stress using Fv/Fm to reveal the physiological mechanism of heat tolerance. *Experimental Environment Botany*, 118: 1-11.



Organic Farming and Fruit Quality: A Scientific Perspective

Surabhi Sharma and Vijay Kumar

Abstract

The majority of studies have confirmed that organically produced fruits excel in quality and taste than those produced from conventional farming through favorable physiological drivers. Organic farming facilitates the plants with enzymes, vitamins and growth stimulants and greater carbon assimilation, high C:N ratio (more carbohydrates), TSS and sugar content and high dry matter content and better sugar: acid ratio for taste, aroma, flavor and storage life besides improving flavonoids, phenolic compounds, anthocyanin, carotene, vitamins, tannins etc in fruits. Several scientists have reported that organic farms maintain an abundant and diverse population of pollinators more than conventional system which promote the fruit set, fruit characteristics and reduces the fruit drop in different fruit crops.

Introduction

Sustainably, productivity and yields are of utmost importance in agriculture. In particular, in context of horticulture, fruit quality is of great concern related to human and environmental health. According to WHO (2026) everyone older than 10 years of age should aim for at least 400 grams of fruits and vegetables per day, with lesser amounts for children under 10: at least 250 or 350 grams for children 2-5 or 6-9 years of age, respectively. Fruit contains essential compounds (anthocyanins and flavonoids), vitamins (vitamin E, vitamin C and those of the vitamin B group), essential mineral nutrients (K, Ca, Mg, P and S and Fe, Zn, or Mn) in very minor quantities. The organoleptic evaluations of fruits for appearance, aroma, flavor, texture, nutritional value and freedom from harmful chemical

compounds are important considerations for the consumers' acceptance. Organic farming provides healthier produce in comparison to conventional farming where in latter there are frequent uses of chemical fertilizers and pesticides. The majority of studies have confirmed that organically produced fruits excel in quality and taste than those produced from conventional farming.

Physiological drivers of organic fruit quality

The fruit biological composition and overall fruit quality in terms of aroma, taste, color, flavor, shape, weight, volume dry matter, antioxidant capacity, nutrients and vitamins contents, shelf-life, biotic and abiotic stress resistance etc. are governed by several physiological factors together under organic as well as conventional farming. The organic farming has an edge over conventional farming in

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improving all these quality parameters through favorable physiological drivers. Microorganisms rich healthy soil facilitates the plants with enzymes, vitamins and growth stimulants. The greater carbon assimilation due to balanced slowly releasing nutrients particularly nitrogen in organic manures ascertain more quantity of carbohydrates, high C:N ratio (more carbon compounds), TSS and sugar content and high dry matter content and better sugar: acid ratio which lead to improvement in taste, aroma, flavor and storage life of fruits. Since organic fruit production usually undergoes through mild biotic and abiotic stress conditions due to minimum or no use of chemical fertilizers and pesticides and under such situation, phenylalanine ammonia lyase enzyme (PAL) is activated resulting into the production of secondary metabolites such as flavonoids, phenolic compounds, anthocyanin, carotene, vitamins, tannins etc. which promote the flavor, color and antioxidants contents in the fruits besides imparting stress resistance in the plants.

Impact on Fruit Quality: Organic fertilizers enhance overall fruit quality compared with chemical fertilizers. Organically produced fruits were found to show improvements in weight, size, firmness, flavor, volatile compounds, macro- and micronutrients, phenolic compounds, antioxidant activity, TSS, organic acids, vitamin C content, sugars and pigmentations (carotenoids) with better consumers' acceptance (Sergi and Núria, 2024). The organoleptic properties of the fruits depend on all these quality traits in the fruits. It has been reported

that use of green manuring along with organic fertilizers improved organoleptic quality and disease resistance in pineapple fruit (Darnaudery *et al.*, 2016). The quality of grapes and citrus were effectively raised by cultivation of cover crops (Fang *et al.*, 2022). The incorporation of compost and organic manures in the soils effectively improved the quality of several fruits such as sweet peppers, strawberries, tomato and mango.

Impact on Pollination and Fruit Quality: It has been confirmed that the pollination is an important factor for the successful production of high-quality fruits. Organic farms maintain an abundant and diverse population of pollinators more than conventional system which promote fruit quality (Table 1). Effective pollination by supporting the pollinating insects under organic farming improves the fruit set, fruit characteristics and reduces the fruit drop in apple, almond, citrus, mango, strawberries, guava, litchi, avocado, pomegranate, papaya, custard apple etc. fruit crops.

Risks and Drawbacks: The conventionally produced fruits and vegetables had more pesticides, nitrate and nitrite residues carcinogenic to human body. Geissen *et al.* (2021) have reported that total pesticide content in organic farming soils is 70-90% lower than in conventional soils. Even though, it is advocated that inorganic fruits are laden with pesticides and fertilizers residues, the organic fruits are also not free of potential risk in food safety. Besides benefits, the compost and organic fertilizers and sewage sludge used as an organic amendments

Table 1: Impact of organic farming on pollination and fruit quality

Fruit	Pollination Effect	Reference
Apples	Higher Initial fruit set and fruit dry matter content and lower K/Ca ratio.	Samnegård <i>et al.</i> (2019)
Pear	Higher production and improved quality.	Fountain <i>et al.</i> (2019)
Kiwi fruit	Enhanced fruit weight, size, and seed content.	Abbate <i>et al.</i> (2021)
Strawberries	Open-pollinated strawberries were larger, redder, better-formed and less acidic than the ones produced without pollination.	Abrol <i>et al.</i> (2019)
Citrus	Increased fruit set, fruit size and seed number.	Sanford (2003)
Guava	Increased fruit set and quality by honey bees as best pollinators.	Rajagopal and Eswarappa (2005)
Litchi	Insect pollination increased fruit yield and quality	Menzel and Waite (2005)
Mango	Bee pollination significantly increased the percent fruit set in mango	Fajardo <i>et al.</i> (2008)
Pomegranate	With subsequent cross pollination, the fruit set increased to around 68 percent and additionally, there was an increase in fruit quality (i.e., number of seeds per fruit and fruit size).	De-shuang <i>et al.</i> (2010)

may be source of non-microbial contaminants such as heavy metals and ,moreover, high mineralization of organic fertilizers may leave nitrate and nitrite residues in organic fruits.

Strategy: There are several factors in both organic and conventional production system like, inherent traits of species, kind of root stocks, nutrient and water management, training and pruning practices, and other pre and post-harvest factors including weather fluctuations and all these factors affect the quality of fruits. Therefore, a multi-pronged strategy is needed in crop cultivation to enhance the fruit quality. Besides it is important to minimize the production gap between organic and conventional farming of fruit crops through sustainable models with integration of all parameters affecting fruit quality along with add-ons with newer production techniques. Harmful residues of pesticides and fertilizers in the soil may be subsided by maintaining the soils biologically active through supplementations of organic fertilizers such as FYM, compost, vermicompost green manures etc. The nutrient enriched soils with active microbial colorizations of fungi, bacteria, actinomyces etc. have shown a

positive long term impact on physiological mechanisms in favor of quality of fruits. Plant growth promoting rhizo-bacteria , VAM and P, K Zn etc. nutrient solublizing bacteria and fungi applied as bio-fertilizers under nutrient deficient conditions are quite useful in maintaining a sustainable organic farming system. The flowering plants like marigold, cosmos, zinnia, aster flower, blanket flower, mustard, beans are the key pollinating plants in the orchards for successful pollination of fruit plants for higher production and quality fruits. It is pre-requisite to avoid the misuse of pesticides to protect the pollinators in the orchards.

References

- Abrol, D. P., Gorka, A. K., Ansari, M. J., Al-Ghamdi, A. and Al-Kahtan, S. (2019). Impact of insect pollinators on yield and fruit quality of strawberry. *Saudi Journal of Biological Sciences*, (26)3: 524-530.
- Fajardo, A. C., Medina, J. R., Oscar Opina, S. and Cervancia, C. R. (2008). Insect pollinators and floral visitors of mango (*Mangifera indica* L. cv. Carabao). *The Philippine Agricultural Scientist*, 91(4): 372-382.

- Abbate, A. P., Campbel, J. W., Edgar, L. Vinson, E. L., Geoffrey, R. and Williams, G. R. (2021). The pollination and fruit quality of two kiwifruit cultivars (*Actinidia chinensis* var. *chinensis* 'AU Golden Sunshine' and 'AU Gulf Coast Gold') (Ericales: Actinidiaceae) grown in the Southeastern United States. *Journal of Economic Entomology*, 114 (2021): 1234-1241.
- Darnaudery, M., Patrick, F. and Léchaudel, M. (2016). Low-input pineapple crops with high quality fruit: promising impacts of locally integrated and organic fertilisation compared to chemical fertilisers. *Experimental Agriculture*, 1(2): 1-17.
- De-shuang, T., Xia, D., Kun, D., Xue-wen, Z. and Yu Yusheng, Y. (2010). Study on the effects of pollination by honey-bees on pomegranate (*Punica granatum* L.). *Journal of Bee*, 3: 10.
- Fang, L., Shi, X., Zhang, Y., Yang, Y., Zhang, X., Wang, X. and Zhang, Y. (2022). The effects of ground cover management on fruit yield and quality: a meta-analysis. *Archives of Agronomy and Soil Science*, 68: 1890-1902.
- Sanford, R. L., Paaby, P., Luvall, J. C. and Phillips, E. (2003). Climate, geomorphology, and aquatic systems. In L. A. McDade, K. S. Bawa, H. A. Hespenheide, and G. S. Hartshorn [eds.], *La Selva: ecology and natural history of a neotropical rain forest*. University of Chicago Press, Chicago, Illinois, USA, 2003, 161-182.
- Fountain, M. T., Mateos-Fierro, Z., Shaw, B., Phil Brain, P. and Alvaro Delgado, A. (2019). Insect pollinators of conference pear (*Pyrus communis* L.) and their contribution to fruit quality. *Journal of Pollination Ecology*, 25(10): 103-114.
- Geissen, V., Vera Silva, V., Lwanga, E. H., Nicolas Beriot, N., Klaas Oostindie, K., Zhaoqi Bin, Z., Pyne, E., Sjors Busink, S., Zomer, P., Mol, H. and Ritsema, C. J. (2021). Cocktails of pesticide residues in conventional and organic farming systems in Europe Legacy of the past and turning point for the future. *Environmental Pollution*, 278: 116827.
- Menzel, C. M. and Waite, G. K. (2005). Litchi and longan: botany, production and uses. CABI Publishing, Wallingford, U.K..
- Rajagopal, D. and Eswarappa, G. (2005). Pollination potentiality of honeybees in increasing productivity of guava in Karnataka. *Advances in Pollen Spore Research*, 22: 131-141.
- Samnegård, U., Hambäck, P. A. and Smith, H. G. (2019). Pollination treatment affects fruit set and modifies marketable and storable fruit quality of commercial apples. *Royal Society Open Science*, 6(12): 190326.
- Sergi Munné-Bosch and Núria F. Bermejo. (2024). Fruit quality in organic and conventional farming: advantages and limitations. *Trends in Plant Science*, (29)8: 878-894.

Millets: Future Crop for Food Security

Gaytri Soni

Introduction

Millets are a group of small-seeded cereal crops that have been cultivated for thousands of years, particularly in Asia and Africa. These crops are known for their ability to grow in harsh environmental conditions such as low rainfall, poor soil fertility, and high temperatures. In the present era of climate change, population growth, and increasing food demand, millets are gaining attention as an important crop for ensuring global food security. Food security means that all people have access to sufficient, safe, and nutritious food to maintain a healthy life. However, major crops like wheat and rice require large amounts of water, fertilizers, and favorable climatic conditions. Due to climate change, water scarcity, and land degradation, it is becoming difficult to depend only on these major crops. Therefore, millets are emerging as a sustainable and climate-resilient alternative. Millets are highly nutritious and rich in fiber, protein, vitamins, and minerals such as iron, calcium, and magnesium. They are also beneficial for health as they help in controlling diabetes, improving digestion, and reducing heart disease risk. Because of their high nutritional value, millets are often called “nutri-cereals.” Another important advantage of millets is that they have a short growing period and require fewer inputs compared to major cereals.

They can be grown in dryland and rainfed areas, making them very important for small and marginal farmers. Millets also help in maintaining soil health and biodiversity. In recent years, the Government of India and international organizations have started promoting millet cultivation and consumption to improve nutritional security and sustainable agriculture. The year 2023 was declared as the International Year of Millets, which increased awareness about the importance of millets in food systems. Thus, millets have the potential to play a major role in future food security, nutritional security, and sustainable agriculture.

Millets and their types

Millets are small-seeded cereal crops that belong to the grass family and are widely grown in dry and semi-arid regions. They are hardy crops that can tolerate drought, high temperature, and poor soil conditions. Millets are highly nutritious and are rich in fiber, protein, minerals, and vitamins. Based on their grain size and importance, millets are generally classified into major millets and minor millets.

Major Millets

Major millets are widely cultivated and consumed in many parts of the world.

Pearl Millet: It is the most widely grown millet in India. It is rich in iron, protein, and fiber and is mainly grown in Rajasthan, Gujarat, and Haryana.

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Sorghum: It is an important millet used for food and fodder. It is rich in carbohydrates and antioxidants.

Finger Millet: It is very rich in calcium and is good for bone health. It is commonly grown in Karnataka and Tamil Nadu.

Minor Millets

Minor millets are small-grained millets and are very nutritious but less commonly grown.

Foxtail Millet: Rich in protein and dietary fiber.

Little Millet: Rich in iron and fiber.

Kodo Millet: Good for diabetic patients due to low glycemic index.

Barnyard Millet: Fast-growing crop, rich in iron.

Proso Millet: Rich in protein and used as bird feed and human food.

Millets as Climate-Resilient Crops

Millets are considered climate-resilient crops because they can grow successfully under harsh environmental conditions where major cereals like rice and wheat often fail. In the context of climate change, rising temperatures, irregular rainfall, drought, and soil degradation are major threats to food production. Millets can play an important role in ensuring stable food production under these changing climatic conditions. One of the main reasons millets are climate-resilient is their low water requirement. Crops like Pearl Millet and Sorghum require much less water compared to rice and wheat. They can grow in areas with rainfall as low as 300-500 mm, making them suitable for arid and semi-arid regions. This makes millets very important for dry-land agriculture. Millets also have a short growing

season. Many millet crops mature within 60-100 days, which helps farmers avoid drought and extreme weather conditions. For example, Foxtail Millet and Barnyard Millet mature quickly and can be grown as short-duration crops. Another important feature of millets is their tolerance to poor soil conditions. Millets can grow in low-fertility soils, saline soils, and even in marginal lands where other crops cannot grow properly. This reduces the need for chemical fertilizers and improves sustainable farming. Millets are also resistant to many pests and diseases, which reduces the need for pesticides. This makes millet cultivation more environmentally friendly and economically beneficial for farmers. Millets also contribute to climate change mitigation. They require fewer inputs such as fertilizers, pesticides, and irrigation, which reduces greenhouse gas emissions. Their deep root system also helps in improving soil structure and preventing soil erosion. Therefore, millets are not only climate-resilient crops but also climate-smart crops. They help farmers adapt to climate change, ensure food security, and support sustainable agriculture.

Nutritional Importance of Millets

Millets are highly nutritious and are often called “Nutri-cereals” because they are rich in protein, fiber, vitamins, and minerals. Compared to major cereals like rice and wheat, millets contain higher amounts of micronutrients such as iron, calcium, magnesium, and zinc. Due to their high nutritional value, millets play an important role in reducing malnutrition and improving human health.

Millets such as Finger Millet are very rich in calcium, which is important for bone development and prevention of osteoporosis. Pearl Millet is rich in iron, which helps in preventing anemia. Foxtail Millet and Little Millet are rich in dietary fiber, which helps in digestion and controls blood sugar levels, making them suitable for diabetic patients. Millets also have a low glycemic index, which means they release glucose slowly into the blood. Therefore, they are good for people suffering from diabetes, obesity, and heart diseases. Millets are also gluten-free, making them suitable for people with gluten intolerance. Millets are important not only for nutritional security but also for food security, especially in developing countries where malnutrition and iron deficiency are major problems. Regular consumption of millets can improve overall health, immunity, and energy levels.

Table 1: Nutrient Content of Millets and Major Cereals (per 100 g)

Crop	Protein (g)	Fiber (g)	Calcium (mg)	Iron (mg)
Finger Millet (Ragi)	7.3	3.6	344	3.9
Pearl Millet (Bajra)	11.6	8.5	42	8.0
Sorghum (Jowar)	10.4	6.7	25	4.1
Foxtail Millet	12.3	8.0	31	2.8
Little Millet	9.7	7.6	17	9.3

Role of Millets on Dryland Agriculture

Dryland agriculture refers to crop production in regions with low and uncertain rainfall, poor soil fertility, and frequent drought conditions. In such areas, crop failure is common, and farmers face high risk in cultivation. Millets play a very important role in dryland agriculture because they can grow under

limited water, high temperature, and low fertility conditions. Millets such as Pearl Millet, Sorghum, and Finger Millet are highly suitable for dryland farming. These crops require less water compared to rice and wheat and can grow in rainfall conditions of about 300-500 mm. Their deep root system helps in extracting moisture from deeper soil layers, which helps the crop survive during drought conditions. Another important role of millets in dryland agriculture is their short duration. Many millet crops mature within 70-100 days, which reduces the risk of crop failure due to drought. For example, Foxtail Millet and Barnyard Millet are short-duration crops and are suitable for areas with a short rainy season. Millets also help in soil health improvement. Their root system improves soil structure and increases soil organic matter. Millets can be grown in poor and marginal soils where other crops cannot grow well. They also require fewer fertilizers and pesticides, which reduces the cost of cultivation for farmers. Millets are also important for fodder and livestock feed in dryland areas. Crops like sorghum and pearl millet provide both grain and fodder, which supports livestock-based farming systems in dry regions. Millets also reduce the risk in rainfed agriculture. Even in low rainfall years, millets can produce some yield, whereas crops like rice may fail completely. Therefore, millets act as a risk management crop for dryland farmers.

Economic Importance of Millets

Millets play a significant role in the economy, especially in developing countries like India,

where a large population depends on agriculture for livelihood. Millets are not only important for food and nutritional security but also for farmers' income, employment generation, and sustainable agricultural development. One of the major economic advantages of millets is their low cost of cultivation. Crops such as Pearl Millet, Sorghum, and Finger Millet require less water, fewer fertilizers, and minimal pesticide use. This reduces the cost of production and increases the profit margin for farmers, especially in dryland and rainfed areas.

Millets also provide income stability to farmers because they can grow in adverse climatic conditions where other crops may fail. Even in drought years, millets produce some yield, which helps farmers avoid total economic loss. Therefore, millets act as a risk-reducing crop in dryland agriculture. Another important economic role of millets is their market demand. In recent years, the demand for millet-based products such as millet flour, biscuits, noodles, and ready-to-eat foods has increased due to rising health awareness. This has created new market opportunities for farmers, food industries, and entrepreneurs. Millets also contribute to the fodder economy. Crops like sorghum and pearl millet provide both grain and fodder, which supports livestock production. This is especially important in rural areas where mixed farming is practiced. Millets also generate employment opportunities in processing, value addition, packaging, and marketing. Small-scale industries related to millet processing, such as flour mills and food product manufacturing,

provide rural employment and support the rural economy. The government is also promoting millet cultivation through minimum support price (MSP), subsidies, and awareness programs. This increases the economic importance of millets and encourages farmers to grow these crops.

Conclusion

Millets are emerging as an important crop for the future due to their nutritional value, climate resilience, and economic benefits. In the present situation of climate change, water scarcity, soil degradation, and increasing population, it is becoming difficult to depend only on major cereals like rice and wheat for food security. Millets offer a sustainable solution to these problems because they can grow in dryland conditions, require fewer inputs, and provide high nutritional value. Millets such as Pearl Millet, Finger Millet, and Sorghum are rich in nutrients, drought-tolerant, and suitable for marginal lands. They provide food, fodder, and income, making them important for farmers as well as consumers. Millets also support sustainable agriculture by improving soil health, reducing water use, and lowering the cost of cultivation. In addition, millets play an important role in nutritional security by providing essential minerals such as iron, calcium, and fiber. They are helpful in reducing malnutrition and lifestyle diseases such as diabetes and heart disease. Their ability to grow under harsh climatic conditions makes them an important crop for dryland agriculture and climate change adaptation. Therefore, millets can be considered as the future crop for

food security, nutritional security, and sustainable agriculture. Increasing awareness, government support, value addition, and proper marketing can further promote millet cultivation and consumption. Millets have the potential to ensure food and livelihood security for present and future generations.



Importance of Dual Purpose Linseed

Smrita Gogoi, Goutami Kataki, Ranjana Chakrabarty and Hemen Kalita

Abstract

Linseed is one of the oldest oilseed crops grown for both fibre and oil. Oil content of linseed varies from 35-45 %. New varieties of linseed have been developed that are capable of producing both high-quality fibre and seed. Linseed holds an important position in Indian agricultural economy due to its wide industrial utility of every part of the plant either directly or after processing. Linseed fibre is one of the most natural & eco-friendly fibres among all textile fibres. Natural fibers such as flax are of immense demand in various industries. Therefore, growing dual purpose linseed or flax is a promising venture for the country to support farmers by doubling their income & promote sustainability by producing versatile natural fibers.

Introduction

Oilseed crops are considered as the predominant crop in Indian agricultural economy after cereals. Linseed also known as flax (*Linum usitatissimum* L.) belongs to the Linaceae family and the genus *Linum* with chromosome no. $2n = 30$, $X = 15$. It is one of the oldest oilseed crops grown for both fiber and oil. Oil content of linseed varies from 33-45% and these oils have been used for centuries as a drying oil (Katoch and Bhatia, 2021). During 2023, global area, production and productivity were approximately 4.53 lakh ha, 3.97 million tonnes and 991 kg ha⁻¹, respectively (<https://www.fao.org/fao-stat/en/#home>, 2024). In Assam during 2022-23, area under linseed cultivation was 4378 ha, producing 2695 tonnes with an average yield of 616 kg ha⁻¹ (Directorate of economics and statistics, Assam). In India, during 2023-24, linseed was cultivated on 2.39 lakh hectares, producing 1.67 lakh tonnes with an

average yield of 698 kg ha⁻¹. Over the five-year period from 2016 to 2021, the cultivated area of linseed showed a decline, but productivity rose significantly from 575 kg ha⁻¹ to 644 kg ha⁻¹, reflecting a positive growth trend. This improvement is attributed to the introduction of high-yielding varieties along with suitable crop management and protection practices (Linseed annual Report, 2023-24, ICAR-Indian Institute of Oilseeds Research Rajendranagar, Hyderabad-500 030).

Linseed was classified into two types by Vavilov: (i) small seeded type-originated from south western Asia and is mainly used for its oil and (ii) bold seed type- originated from Mediterranean region and is used for its fibre (Singh *et al.*, 2022). The growth habit of the three linseed types differs from one another. Seed-type linseed plants are relatively short, usually 30-50 cm tall, and produce many branches from the base with a higher number

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of capsules. In contrast, the flax type grows much taller, about 100-120 cm in height, with only a few branches confined to the upper part of the plant. With advancements in research under the AICRP on Linseed, new varieties have been developed that are capable of producing both high-quality fibre and seed. These dual-purpose types typically grow to a height of 75-100 cm, possess a technical height (distance from the ground to the first branching point) of over 50 cm, and carry more branches concentrated in the upper portion of the plant (Singh *et al.*, 2018).

Linseed oils with high industrial values

Linseed contains about 33-47% oil. Linseed oil has its own unique versatile drying property. So when this oil is exposed to oxygen in air it is converted to solid form. This property makes it useful either on its own or by blending with other oils, solvents and resins etc. Linseed oils can be used in the manufacture industries of paints, varnish, waterproof materials, patent leather (Japaned leather) and special finishes for cotton and silk fabrics etc. Oil is also used as finishing oil in wooden furniture which prevents it from denting (Katoch and Bhatia, 2021).

Linseed fiber: one of the most natural and eco-friendly fibers along with the industrial value

Linseed holds an important position in Indian agricultural economy due to its wide industrial utility of every part of the plant either directly or after processing. Linseed is mainly grown as oilseed crop; but it is also grown for its fibre called linen or flax.

As research work in linseed is increasing; it resulted in release of many dual-purpose varieties which can be used both for its seed as well as its fibre. Flax is used in textile industries for producing high quality, soft clothes which have a great sweat absorbent capacity making it appropriate for summers. Linseed fiber is one of the most natural and eco-friendly fibers among all textile fibers. It is known for its strength, fineness, lustrous, less stretchy and durable in nature. They have more tolerant ability to environmental fluctuation than the other fiber crops cotton and jute. Linseed fibers blend very well with other textile fibers wool, silk, cotton etc. These fibers are used for making shoes, fishing lines and nets. They are also extensively used as raw materials to manufacture canvas, twine, carpets, blankets and rugs. Rough and coarser grade fibers are used in the manufacture of strong ropes, shipping cord, twines and cordage, which are very crucial for aeronautical and defense purposes. Linseed or flax fibre textiles are called 'linen' or 'linso-fabrics'. The best grades of flax fibers are used for making suits, shirts, bedsheets, cloth laces and curtains. Flax-jute (Linju) and Flax-cotton (Linco) blended fabrics offer better quality compared to pure jute or cotton fabrics (Pandey and Dayal, 2003). Linseed fibers are considered a good substitute for mineral fibers due to its low density, high specific stiffness and recyclability or biodegradable in nature. These qualities make them useful as rigid composite materials (Baley, 2002), and a sustainable alternative as biocomposites in various industries (Bensadoun *et*

al., 2016). Coarse and fine flax fibres are also used in geotextiles for insulation offering environmental benefits such as biodegradability and a sustainable alternative to synthetic fibers (Khan *et al.*, 2022). After extracting the fibers from the stalk, the woody core and short fibers are used as raw materials for making high quality paper; which are used in preparing of currency notes, air mail, parchment paper, good writing paper of different economic values (Singh *et al.*, 2018).

Dual purpose Linseed variety recommended for Assam

Variety name: JRF-2 (Tiara)

Notification no.: S.O.1228 (E)

Year of release: 2015

Developed by: Sunnhemp Research Station, Pratapgarh

Area of adaption: Himachal Pradesh, Punjab, Haryana, Jammu and Kashmir, Uttar Pradesh, Bihar, West Bengal and Assam

Days to maturity: 100-110 days

Average yield (kg ha⁻¹): 1290 (Seed), 1204 (Fibre)

Oil content: 39%

Plant height: 100-125 cm

Special feature(s): First fibre flax variety of India

Source: <https://icar-iior.org.in/linseed>

Seed availability: Might be available at Sunnhemp Research Station, Pratapgarh or ICAR-CRIJAF, Barrackpore, West Bengal.

Profitability: Dual-purpose linseed varieties, which are cultivated for both seed (oil) and fiber, offer significantly higher profitability compared to

traditional seed-only or fiber-only types. These dual-purpose linseed varieties, such as JRF-2 can yield both a substantial seed harvest and valuable fiber, resulting in a higher net return and a better Benefit-Cost (B:C) ratio. Studies shows that net monetary returns from dual-purpose linseed can be double than that of traditional seed-only types. The B:C ratio for improved dual-purpose varieties has been recorded as high as 4.24.

Fibre extraction technology: Linseed plants are usually first harvested for the recovery of the seeds. In this process, the linseed is either mown completely and the straw is deposited on the field, or in some cases the seeds are also stripped, leaving the stalk component and possibly requiring mowing in a further process step. Subsequently, this biomass remains on the field surface for field drying and retting. Retting is the biodegradation process of pectin and other matrix polysaccharides in the plant stems by the enzymes of microorganisms, bacteria and/or fungi. The pectins and polysaccharides act as an adhesive in the plant stem and after their degradation, the fibres can be separated mechanically (flax fiber extractor) more easily from the non-fibre tissues. There are three main retting methods known: a. water, b. dew and c. enzyme-retting (Mańkowski *et al.*, 2017; Sadrmanesh and Chen, 2019) followed by mechanical techniques like breaking, carding, or specialized “all-fibre” extraction machines (e.g., Laroche Cadette 1000 MDPI). These methods enable processing of residual straw into high-quality fibres for textiles and industrial

applications.

- ✓ In water-retting, which was formerly the most used method, the microorganisms decompose the adhesive tissues in a controlled aqueous environment (Sadrmanesh and Chen, 2019). The resulting fibres are uniform and of high quality (Morrison *et al.*, 2000), but this method produces a high amount of wastewater (Keller *et al.*, 2001) and the cost of its treatment (compulsory in the European Union) is generally too high.
- ✓ In dew-retting, which is currently the most used method in bast fibre production, the stems are left in the field (Fouk *et al.*, 2000). Moisture from dew and precipitation create conditions that favour the growth of microorganisms for the degradation of pectins and polysaccharides. Respective investigations on the duration underline this by detailed analysis of the content of structural components during dew retting, for a period of 6 weeks (Khan, 2022). In comparison to water-retting this technique is low-cost and water- saving. However, dew-retting depends on climate and weather conditions and is difficult to control, so there is the risk of over- or under-retting (Dhakal and Zhang, 2015).
- ✓ Enzyme-retting circumvents the problems of weather conditions and wastewater production (Sadrmanesh and Chen, 2019). It was developed in Europe as a method to replace dew-retting (Akin *et al.*, 2001). In this treatment commercial enzymes containing chelators are sprayed onto the plant stems and cause the rapid and efficient

production of fibres with a high, consistent quality (Akin *et al.*, 2001; Sadrmanesh and Chen, 2019).

Mechanical Extraction Methods

Method A: Uses horizontal breaker rollers followed by a breaking card to break down the stem and separate fibres.

Method B: Uses a Laroche Cadette 1000 “all-fibre” extractor with vertical breakers and a suction-assisted sieving step to clean the fibres.

Conclusion

Overall, linseed (*Linum usitatissimum*) is a multipurpose crop valued for its oil, fiber, nutritional, medicinal, and industrial applications. Rich in α -linolenic acid, lignans, proteins, fiber, phenolics, and vitamins, it serves as an excellent functional food with proven health benefits. Linseed is a valuable crop due to its versatile properties and offers a more sustainable alternative to fast fashion. It requires less pesticides and water compared to other crops used in textile production, such as cotton (<https://cropsandsoils.extension.wisc.edu/flax>).

Clothes made up from synthetic fibers such as polyester, nylon, and acrylic; release microfibers and nano-plastic materials into the environment. These particles can persist in landfills for hundreds of years and contributing to climate change through fossil fuel use and greenhouse gas emissions. Uses of natural fibers in varied industries are a current area of intense interest. Therefore, growing dual purpose linseed is a promising venture for the state to support farmers by doubling their income and promotes

sustainability by producing versatile natural fibers. For linseed to succeed as a diversified crop, we must simultaneously increase area under linseed cultivation, improving mechanization for harvesting, threshing and fiber processing, and strengthening market access for farmers to ensure profitability and sustainability. So, more research work should be initiated to breed double purpose linseed varieties along with improved fiber quality by breeding/agronomic manipulations, which would save a huge amount of foreign exchange and will generate more employment. With rising consumer focus on health and nutrition along with the industrial value as natural fiber, dual purpose linseed holds tremendous potential to emerge as a major oilseed and fiber crop in the future.

References

- Akin, D., Foulk, J., Dodd, R. and McAlister III, D. (2001). Enzyme-retting of flax and characterization of processed fibers. In: *Journal of Biotechnology*, Vol 89. Elsevier Ltd, Amsterdam, NL, pp. 193-203.
- Baley, C. (2002). Analysis of the flax fibres tensile behaviour and analysis of the tensile stiffness increase. *Composites Part A: Applied Science and Manufacturing*, 33(7): 939-948.
- Morrison III, W., Archibald, D. D., Sharma, H. S. S. and Akin, D. E. (2000). Chemical and physical characterization of water- and dew-retted flax fibers. In: *Industrial Crops and Products*, Vol 12. Elsevier Ltd, Amsterdam, NL, pp. 39-46.
- Bensadoun, F., Vanderfeesten, B., Verpoest, I., Van Vuure, A. W. and Van Acker, K. (2016). Environmental impact assessment of end of life options for flax-MAPP composites. *Industrial Crops and Products*, 94: 327-341.
- Dhakal, H. and Zhang, Z. (2015). The use of hemp fibers as reinforcements in composites. Bio-fiber reinforcements in composite materials. Woodhead Publishing (Elsevier Ltd, Amsterdam, NL, pp. 86-103.
- Katoch, M. and Bhatia, N. S. (2021). Linseed and its basic composition. *International Journal of Advances in Agricultural Science and Technology*, 8(6): 10-26.
- Khan, S. U., Bar, M., Evon, P., Labonne, L. and Ouagne, P. (2022). Development of 100% linseed flax yarns with improved mechanical properties and durability for geotextiles applications. *Fibers*, 10(12): 102.
- Mańkowski, J., Maksymiuk, W., Spychalski, G., Kołodziej, J., Kubacki, A., Kupka, D. and Pudelko, K. (2017). Research on new technology of fiber flax harvesting. *Journal of Natural Fibers*. Taylor & Friends, Abingdon, UK. <https://doi.org/10.1080/15440478.2017.1302390>.
- Pandey, R. and Dayal, R. (2003): Flax-Jute and Flax-Cotton Blended Fabric. *Asian Textile Journal*, 12(7): 51-55.
- Singh, C., Singh, R. and Singh, P. (2022). Modern techniques of raising field crops. CBS Publishers & Distributions Pvt Ltd: 380-389.

- Sadrmanesh, V. and Chen, Y., 2019. Bast fibers structure processing properties and applications. In: International Materials Reviews, Vol 64. Taylor & Friends, Abingdon, UK, pp. 381-403.
- Keller, A., Leupin, M., Mediavilla, V. and Wintermantel, E. (2001). Influence of the growth stage of industrial hemp on chemical and physical properties of the fibers. In: *Industrial Crops and Products*, Vol 13. Elsevier Ltd, Amsterdam, NL, pp. 35-48.
- Foulk, J., Akin, D. E. and Dodd, R. B. (2000). New low cost flax fibers for composites. *Society of Automobile Engineering*, 2000. *International World Congress*, 11 <https://doi.org/10.4271/2000-01-1133>.
- Khan, S. U. (2022): Complete valorisation of linseed flax straw in geotextiles and particleboards. *Mechanics of materials* [physics.class-ph]. Institut National Polytechnique de Toulouse -INPT, 2022. English. NNT: 2022INPT0004.
- Singh, P. K. and Chopra, P. (2018). Double purpose linseed: a viable option for doubling farmers' income in the north-western Himalyan region. *Indian Farming*, 68(1).

The Silent Boosters of Pineapple Growth

Abhisek Rout and Roshan Kumar Pradhan

Abstract

Pineapple (*Ananas comosus* L. Merr.), recognized as one of the most significant tropical fruit crops, is esteemed for its distinctive flavor, nutritional value, and economic importance. However, achieving optimal growth, yield, and fruit quality is heavily reliant on balanced nutrient management, particularly the availability of essential micronutrients. This article underscores the vital roles of key micronutrients iron, zinc, copper, and boron in pineapple cultivation, highlighting their participation in physiological processes such as enzyme activation, chlorophyll synthesis, hormone regulation, and nutrient transport. Deficiencies in these micronutrients can result in various physiological disorders, including chlorosis, stunted growth, leaf deformation, and inadequate fruit development. For example, a lack of iron hampers chlorophyll production, zinc deficiency interferes with growth hormone synthesis, copper deficiency is linked to structural issues such as “crook-neck,” and boron deficiency critically affects vascular function and fruit quality. These deficiencies not only impair plant vigor but also considerably reduce yield and market value. The article also explores the causes, symptoms, and practical management strategies for rectifying micronutrient imbalances, including soil and foliar applications. By comprehending and addressing these nutritional limitations, farmers can enhance crop health, improve fruit quality, and ensure sustainable pineapple production. This thorough overview aims to offer valuable insights for growers, researchers, and agricultural practitioners who are looking to optimize pineapple cultivation through effective micronutrient management.

Introduction

Pineapple (*Ananas comosus* (L.) Merr.), belonging to the Bromeliaceae family, is recognized as one of the most beloved tropical fruits worldwide. Often referred to as the “queen of fruits,” it is esteemed for its vibrant fragrance, unique sweetness, and invigorating tang. In terms of global significance, pineapples are ranked just after bananas and citrus fruits, making them the third most important

tropical fruit crop globally. A primary factor contributing to the widespread appeal of pineapple is its versatility. It can be enjoyed in various forms fresh slices, cooked dishes, juices, canned products, and preserves. However, despite its popularity, pineapple is both seasonal and highly perishable, presenting challenges for storage and transportation. A fully ripened pineapple generally contains about 14% natural sugars, which adds to its distinctive

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sweetness, while also providing a rich array of organic acids and nutrients. Nutritionally, pineapple offers more than just a delightful flavor. It is rich in essential compounds such as citric acid and malic acid, which enhance its balanced taste and digestive advantages. Additionally, it serves as a good source of vitamin A and B-complex vitamins, promoting overall health. One of its most notable components is bromelain, a proteolytic enzyme recognized for its capacity to break down proteins into simpler amino acids. This enzyme not only facilitates digestion but has also garnered interest for its therapeutic properties, making pineapple a valuable addition to various dietary and medicinal practices. The flavor profile and chemical makeup of pineapple juice can differ significantly based on several factors. Geographic location, climatic conditions, harvest timing, and processing methods all play a role in determining the final taste and quality. The fruit's distinctive flavor results from a harmonious interplay between its sugar content and acidity, which together produce its refreshing and appealing taste. On a global scale, pineapple cultivation is primarily concentrated in tropical and subtropical regions.

Nutritional Value of Pineapple: Pineapple is a highly regarded tropical fruit, esteemed not only for its succulent texture and invigorating flavor but also for its remarkable nutritional composition. It offers a range of vital nutrients including calcium, potassium, vitamin C, carbohydrates, dietary fiber, and a significant water content. Collectively, these elements are crucial in aiding digestion, sustaining a healthy body

weight, and fostering overall health. In numerous tropical nations, such as Bangladesh, pineapple is a prevalent dietary option, particularly appreciated for its naturally low levels of fat and sodium. The edible part of pineapple has been thoroughly examined for its nutritional makeup. It is primarily composed of moisture, which typically varies from approximately 81% to 86%, contributing to its hydrating qualities. The remaining 13% to 19% consists of total solids, predominantly carbohydrates. Sugars like sucrose, glucose, and fructose make up nearly 85% of these solids, imparting the fruit's distinctive sweetness. Although dietary fiber is present in smaller quantities (around 2-3%), it is essential for digestive health.

Among the organic acids present in pineapple, citric acid is the most prevalent, providing the fruit with its mildly tart flavor. Besides carbohydrates and acids, pineapple pulp contains only minimal amounts of ash, lipids (about 0.1%), and nitrogenous compounds. Of these nitrogenous elements, approximately one-quarter to one-third are classified as true proteins. Importantly, a substantial portion of these proteins nearly 80% demonstrates proteolytic activity due to the presence of bromelain, a naturally occurring enzyme that facilitates the breakdown of proteins into simpler forms, thereby improving digestion. Pineapple is also an important source of essential minerals. It contains significant quantities of calcium, chlorine, potassium, phosphorus and sodium, all of which are vital for maintaining proper physiological functions such as nerve signaling, muscle contraction and fluid balance.

One of the most notable nutritional benefits of pineapple is its substantial vitamin C (ascorbic acid) content. This potent antioxidant plays a crucial role in bolstering the immune system, safeguarding the body from infections, and enhancing the absorption of iron from plant-derived foods. In fact, just half a cup of pineapple juice can deliver approximately half of the recommended daily allowance of vitamin C for an adult. Moreover, in addition to these key nutrients, pineapple provides small yet significant amounts of trace minerals such as manganese and copper. These micronutrients are vital for bone growth, enzyme activation, effective iron metabolism, and the regulation of heart function and blood pressure.



Fig. 1: Health Benefits of pineapple

Role of Micronutrient in Pineapple: The proper growth and development of pineapple is contingent upon a well-balanced supply of essential nutrients. Among the sixteen elements necessary for plants, both macronutrients and micronutrients are vital in sustaining appropriate physiological and biochemical functions. Essential nutrients such as nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), and sulphur (S), along with micronutrients including iron (Fe), zinc (Zn), copper (Cu), and boron (B), are critical to the overall meta-

bolism of the pineapple plant. These nutrients play an active role in the formation of plant tissues and the accumulation of dry matter. They also act as essential components or activators of various enzymes that govern metabolic processes. In the case of pineapple, the behavior of nutrients may vary slightly from that of other crops due to its unique growth pattern, shallow root system, and specific physiological traits. Consequently, meticulous nutrient management is particularly crucial for attaining optimal growth and fruit quality.



Fig. 2: Essential guide to pineapple micronutrients

Iron in Pineapple Nutrition: Iron is a crucial micronutrient that significantly contributes to the growth and metabolic functions of pineapple plants. It serves as a vital element in various essential enzymes and primarily acts as a redox catalyst, enabling important biochemical reactions. These reactions encompass the breakdown of carbohydrates and the reduction of sulphates and nitrates, which are essential for the plant's energy production and nutrient uptake. While iron is not a direct component of chlorophyll, it is essential for its production. Consequently, a sufficient supply of iron is necessary to preserve the healthy green color of leaves and to promote effective photosynthesis.

Iron Deficiency in Pineapple: Iron deficiency is a prevalent nutritional issue in pineapple farming, especially in calcareous soils (those rich in lime) or soils with a high pH. In such environments, iron becomes less accessible to plants, even when it is present in the soil. A deficiency of iron negatively impacts chlorophyll production and protein synthesis, resulting in stunted growth and diminished fruit yield. The movement of iron within the plant is also restricted. When phosphates are in excess, they can further limit the mobility and absorption of iron. Moreover, elevated levels of manganese in the soil may hinder iron availability, exacerbating deficiency symptoms. In regions where pineapples are cultivated, a condition often termed “calcium chlorosis” is frequently associated with lime-rich soils and is closely related to iron deficiency.

Symptoms of Iron Deficiency: The most notable symptom of iron deficiency is chlorosis, which is marked by the loss of green color in leaves. This condition usually manifests first in the youngest leaves situated in the central rosette of the plant. It is crucial to differentiate iron deficiency from nitrogen deficiency, as both can lead to yellowing. However, nitrogen deficiency typically affects older leaves first, whereas iron deficiency initiates in the younger leaves.

Treatment and Management: Iron deficiency can be effectively addressed through the foliar application of iron-rich compounds. A commonly utilized technique involves the direct spraying of a 3% ferrous sulphate solution onto the leaves.

This method has been successfully implemented in prominent pineapple cultivation areas such as Queensland, Hawaii, and Puerto Rico. In numerous commercial plantations, ferrous sulphate is integrated into standard fertilizer regimens as a precautionary strategy. The frequency of application may differ based on the plant's growth stage. For example, in Hawaii, young pineapple plants are generally treated every two weeks, whereas mature plants are treated approximately once a month.

Zinc in Pineapple: Zinc is an essential micronutrient necessary for the optimal growth and development of pineapple plants. It plays a significant role in the synthesis of tryptophan, an amino acid that acts as a precursor for the production of indole acetic acid (IAA), a crucial plant growth hormone. This hormone regulates various growth processes, including cell elongation and differentiation. In addition to its function in hormone production, zinc is a vital component or activator of several key enzymes. These include alcohol dehydrogenase, lactic acid dehydrogenase, glutamic dehydrogenase, and carbonic anhydrase, all of which are involved in important metabolic pathways such as respiration and protein synthesis. Through these roles, zinc significantly contributes to the overall health and productivity of the pineapple plant.

Zinc Deficiency: Zinc deficiency is frequently observed in soils that are sandy or peaty in nature, particularly where nutrient leaching is prevalent. Such soils often struggle to retain essential micro-nutrients, rendering them less accessible to plants.

Highly acidic soils with low pH levels can also restrict zinc availability. Even well-drained soils with low organic matter (humus) may display zinc deficiency if nutrients have been washed away over time.

Symptoms of Zinc Deficiency: The symptoms of zinc deficiency in pineapple plants are quite distinctive. One of the initial signs is the emergence of small or large, transparent yellowish spots on the leaves. As the deficiency advances, the young leaves within the central rosette begin to curl and twist abnormally.

With increasing severity, the leaves become narrower and thinner, and their color gradually shifts from healthy green to pale yellow. In many instances, a thick, waxy coating develops on the leaf surface, imparting an unusual texture. In advanced stages, the inner leaves may bend sideways and downward, forming compact clusters. This gives the plant a distorted appearance resembling a calabash fruit. This condition is commonly referred to as “Crook-neck disease” arises from disrupted growth patterns resulting from insufficient zinc supply. A notable feature of zinc deficiency is its irregular manifestation in the field. Affected plants may be found sporadically, growing alongside entirely healthy specimens, complicating the diagnostic process.

Management of Zinc Deficiency: Zinc deficiency in pineapple can be effectively addressed through foliar application. A widely recommended method involves spraying the plants with a 1% zinc sulphate solution. Generally, a spray volume of approxi-

mately 200 liters ha⁻¹ equivalent to around 20 kg of zinc sulphate ha⁻¹ is adequate to rectify moderate deficiency. In instances of severe deficiency, multiple applications may be required to restore the plant's health. Consistent zinc supplementation not only rectifies nutrient imbalances but also improves fruit quality and fosters robust root development. This leads to enhanced nutrient absorption and overall plant vitality, ultimately resulting in increased yield.

Copper in Pineapple: Copper is another vital micronutrient necessary for the healthy growth of pineapple plants. A substantial portion nearly 70% of the plant's copper is located in the chloroplasts, where it plays a pivotal role in various physiological processes. Copper is essential for activating several key enzymes, including tyrosinase, cytochrome oxidase, polyphenol oxidase, ascorbic acid oxidase, and phenolase. These enzymes are crucial for processes such as respiration, photosynthesis, and oxidation-reduction reactions. Through these roles, copper aids in plant metabolism, structural stability, and stress resistance.

Copper Deficiency: Copper deficiency in pineapple is frequently linked to a disorder known as “Crook-neck disease,” which is also associated with zinc deficiency. In plants lacking copper, the leaves become noticeably thinner and narrower than usual. The younger leaves are especially impacted, appearing shorter, more slender, and weaker. As the deficiency advances, plant growth becomes significantly stunted. In severe cases, the condition may

result in plant death if timely corrective actions are not implemented. Another disorder associated with copper deficiency is “green die-back,” which was first documented in Malaya. In this condition, the plant begins to die back from the tips of the leaves.

Management of Copper Deficiency

Copper deficiency in pineapple necessitates meticulous management, as improper application techniques can harm the plant. Foliar spraying of copper sulphate is typically discouraged due to the risk of leaf burn from its corrosive properties. Instead, applying it to the soil is regarded as a safer and more effective method. A prevalent practice involves administering a 1.5-2% copper sulphate solution directly to the soil, ensuring a distance of approximately 5-8 cm from the plant's base. Generally, 30-50 ml of this solution per plant is adequate to rectify the deficiency. This precise application guarantees that the nutrient is absorbed through the roots without damaging the leaves. Given that copper sulphate is highly corrosive, it is crucial to refrain from using metal containers for the preparation or application of the solution. Non-metallic containers, such as those made of plastic or earthen materials, are more appropriate for this task. In areas where issues like “Crook-neck disease” have been previously identified, preventive strategies become vital. Incorporating 25-40 kg of copper sulphate per hectare into the soil during replanting has been shown to effectively reduce the likelihood of recurrence. Furthermore, an annual application of approximately 10-17 kg ha⁻¹, in conjunction with

regular fertilizers, aids in preventing conditions such as “green die-back” and promotes ongoing plant health and productivity.

Boron in Pineapple: Boron is another essential micronutrient necessary for the optimal growth and development of pineapple plants. It plays a pivotal role in preserving the integrity and permeability of cell membranes, which is critical for the regulated movement of nutrients within the plant. One of boron's primary functions is to enhance the absorption of cations, or positively charged ions, such as calcium and potassium. Concurrently, it assists in regulating and limiting the uptake of anions (negatively charged ions), thereby maintaining a balanced nutrient environment within plant tissues.

Impact of Boron Deficiency: Boron deficiency in pineapple significantly affects the plant's internal transport mechanisms. One of the most crucial consequences is the damage or failure of vascular tissues, including the cambium and phloem. These tissues play a vital role in the transportation of water, nutrients, and sugars throughout the plant. When there is a lack of boron, this transport system is compromised. Consequently, sugars and nitrogenous compounds start to accumulate in the leaves rather than being distributed to other areas of the plant. This disruption adversely affects overall growth, weakens plant development and diminishes nutrient utilization efficiency.

Indicators of Boron Deficiency: In contrast to many other nutrient deficiencies, boron deficiency in pineapple does not consistently manifest clear or

early visual symptoms on the leaves. Instead, its effects are more distinctly observed during fruit development. Fruits that develop under boron-deficient conditions are typically smaller than usual and often do not mature properly. A notable symptom is the appearance of cracks between the fruitlets, which may become filled with a viscous substance. These deformities compromise both the quality and market value of the fruit. In extreme cases, the consequences can be even more severe. Plants may either completely fail to produce fruit or yield very small, misshapen fruits that are unfit for consumption or sale.

Conclusion

Pineapple is not only a delightful tropical fruit but also serves as a significant source of essential micronutrients that greatly benefit human health. The inclusion of vitamins, particularly vitamin C, along with vital minerals such as calcium, potassium, magnesium, and trace elements like manganese and copper, aids various bodily functions, including immune defense, bone strength, and metabolic processes. Although these micronutrients are needed in small amounts, they play a crucial role in sustaining overall health and preventing nutritional deficiencies. Therefore, incorporating pineapple into one's diet can be an effective method to naturally boost micronutrient intake.

References

Book Pineapple (ICAR) by K. L. Chadha, B. M. C. Read, S. D. Shikhamany.

Amin, M. N., Rahman, M. M., Rahman, K. W., Ahmed, R., Hossain, M. S. and Ahmed, M. B. (2005). Large scale plant regeneration in vitro from leaf derived callus cultures of pineapple (*Anana comosus* L. Merr. Cv. Giant Kew). *International Journal of Botany*, 1(2): 128-1323.

Ghosh, S. N., Roy, S., Bera, B. and Kundu, A. (2013). Effect of organic and inorganic nutrition on production of pineapple grown as intercrop in mango orchard in laterite soil. *Indian Journal of Fertilisers*, 9(11): 30-33.

Rohrbach, K. G., Leal, F. and Coppens d'Eeckenbrugge, G. C. (2003). History, distribution and world production. In: *The Pineapple: Botany, Production and Uses*. Bartholomew, D. P., Paull, R. E. and Rohrbach, K. G. (eds). CABI Publishing, New York, USA. pp. 1-12.

Rojas, W. U. and Solidum, P. P, 1990. Effect of different ethrel concentrations on the flowering and fruit setting of pineapple (*Ananas comosus* L.). *CMU Journal of Science*, 3(2): 25-32.

Small Millets as Climate-Resilient and Nutri-Cereals for Sustainable Agriculture

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Small millets are small grained cereal crops that are highly nutritious and are commonly known as nutri-cereals and miracle grains. Small millets are rainfed crops often grown under marginal/low fertile soils with very low inputs such as fertilizers and pesticides. Seven crops *i.e.*, finger millet (ragi/mandua), foxtail millet (kangni/Italian millet), little millet (kutki), kodo millet, barnyard millet (sawan/jhangora), proso millet (cheena/common millet), and brown top millet (korale) are categorized as small millets. These crops largely contribute to food and nutritional security of the country. Most of millet crops are native to India. Millets were the first crops domesticated by the mankind in Asia and Africa and they later spread across the globe as critical food sources to the evolving civilizations.

Millets serve as a nutritional powerhouse, offering a rich array of both macro and micro-nutrients. They are recognized for their nutraceutical benefits, including antidiabetic and antihypertensive properties. The composition of millet grains includes 65-75% carbohydrates, 6-8% proteins, 1-1.7% fats, 18%-20% dietary fibers, and 2-2.5% minerals, enriched with essential vitamins and bioactive comp-

ounds such as phytates, tannins and poly-phenols (Chethan and Malleshi, 2007; Malleshi and Hadimani, 1993). This nutritional profile positions millets as nutritionally superior to major cereals like wheat, rice, and maize. The endosperm of millet grains is notably concentrated in starch, proteins, fats, and a modest amount of fibers, underscoring their value in a balanced diet (Rao et al., 2018). Among micronutrients various trace elements, vitamins and carotenoids are the important constituents in millets. Small millets have exceptional adaptability. Unlike major cereals with high fertilizer requirements, they thrive in marginal lands with low nutrient availability and minimal water resources making them eco-friendly. Small millets have shorter growing duration, complete their life cycle in 2-4 months and are compatible with a wide range of cropping systems and adapt to changing environmental conditions especially during vagaries of the monsoon (Mukherjee *et al.*, 2025).

Changes in monsoons are evident now-a-days. Delay in onset of monsoons thus affecting the sowing window reduces the yield of majority of crops. Small millets are often considered as conting-

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ent crops. Their short duration makes them escape adversity of weather conditions and produces substantial yields compared to other crops like rice and wheat. In addition to this their short life cycles, inherent pest and disease resistance, and extended shelf life contribute to their suitability for rainfed regions. This resilience allows them to flourish in challenging environments where other crops struggle. Millets possess a unique advantage in the form of the C_4 photosynthetic pathway. Unlike the C_3 pathway used by major cereals like rice and wheat, C_4 photosynthesis employs a more efficient mechanism for carbon dioxide fixation. This allows millets to concentrate CO_2 around the enzyme responsible for its assimilation, boosting their photosynthetic efficiency, particularly in hot and dry environments. While the C_4 pathway requires slightly more energy, the benefits outweigh the drawbacks. This enhanced efficiency translates into improved water-use efficiency, allowing millets to thrive in conditions where C_3 plants struggle. Small millets tiny leaf area, thickened cell walls, and capacity to establish dense root systems are some of the characteristics that help them avoid the prevalence of stress conditions and their effects (Li and Brutnell, 2011). They also showed enhanced levels of reactive oxygen species, antioxidants and stress combating enzyme (catalase and superoxide dismutase) activity during abiotic stress situations. Millets have a substantially smaller carbon footprint than other crops, which can reduce the global carbon impact also.

Climate change poses a substantial risk to global food security. Now days the frequency and severity of extreme weather events such as droughts, floods and heat waves affect agricultural production. While climate change threatens crop productivity, millet can also play a vital role in mitigating nutritional deficiencies associated with changing weather patterns. Despite their potential as a solution to pressing challenges in food security, climate adaptation and malnutrition, millets remain under-utilized. Millets are now renamed from poor man's crops to nutri-cereals and are becoming staple food crops to varied consumers.

Table 1: Climate resilient traits of millets

Crop	Days to maturity	Salient features
Pearl millet	80-95	Highly resilient to heat and drought, come up in very poor soils, but are responsive to high input management
Sorghum	100-125	Drought tolerant, excellent recovery mechanism from stresses, highly adapted to wide range of soils, altitudes and temperatures, responsive to high input management
Finger millet	90-130	Moderately resistant to heat, drought and humidity, adapted to wide altitude range
Foxtail millet	70-120	Adapted to low rainfall, high altitude
Kodo millet	100-12	Long duration, but very hardy, needs little rainfall, comes up in very poor soils, good response to improved management
Barnyard millet	45-60	Very short duration, not limited by moisture, high altitude adaptability
Little millet	70-110	Adapted to low rainfall and poor soils- famine food; withstands waterlogging to some extent
Proso millet	60-90	Short duration, low rainfall, high altitude adapted
Brown top millet	60-80	Short duration, adapted to poor soils with less rainfall

Millet-Low water consumers: One of the most attractive qualities of millets is their exceptional drought tolerance. Unlike major cereals like rice and maize, which require significantly higher water inputs, millets require considerably less water during their growth period. This inherent water efficiency makes millets a beacon of hope in regions facing water scarcity. Requiring significantly less irrigation, millets offer a sustainable alternative, reducing the strain on precious water resources.

Crop	Water requirement to produce 1 kg yield
Rice	5000
Wheat	750
Maize	750
Sorghum	833
Pearl millet	667
Finger millet	1000
Other millets	1111

(Source: The story of millets)

Conclusion

Small millets are important climate-resilient nutri-cereals due to their ability to tolerate drought, high temperature, and poor soils. They require less water and inputs, making them suitable for rainfed and dryland agriculture. Their rich nutritional composition contributes to food and nutritional security. Small millets ensure stable yields under changing climatic conditions. Therefore, they play a crucial role in promoting sustainable and climate-resilient agriculture

References

Rao, B. D., Ananthan, R., Hariprasanna, K., Bhatt, V., Rajeswari, K., Sharma, S., *et al.* (2018). *Nutritional and Health Bbenefits of Nutri cereals*. Nutri Hub TBI, ICAR-Indian Institute of Millets Research.

Chethan, S. and Malleshi, N. G. (2007). Finger millet polyphenols: Optimization of extraction and the effect of pH on their stability. *Food Chemistry*, 105: 862-872.

Li, P. and Brutnell, T. P. (2011). *Setaria viridis* and *Setaria italica*, model genetic systems for the panicoid grasses. *Journal of Experimental Botany*, 62: 3031-3037.

Malleshi, N. G. and Hadimani, N. A. (1993). Nutritional and technological characteristics of small millets and preparation of value-added products from them. In K. W. Riley, S. C. Gupta, A. Seetharam, & J. N. Mushonga (Eds.), *Advances in Small Millets* (pp. 271-287). Oxford & IBH Publishing Co. Pvt. Ltd.

Mukherjee, B., Jha, R. K., Sattar, A., Dutta, S., Bhattacharya, U., Samanta, S., Huirem, B., Singh, S. K., Das, S. and Bal, S. K. (2025). Harnessing the potential of millets for climate-resilient and sustainable agriculture. *Frontiers in Plant Science*, 16: 1574699.

Bhat, B. V., Rao, B. D. and Tonap, V. A. (Eds.). (2018). *The Story of Millets*. Indian Institute of Millets Research.

Effect of Semiochemicals on Natural Enemies

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Abstract

Semiochemicals are chemical signals that mediate interactions within and between species, profoundly influencing relationships among plants, herbivores, and natural enemies in agroecosystems. These compounds including pheromones and allelochemicals such as kairomones, synomones, and allomones regulate host location, foraging, oviposition, and retention of parasitoids and predators. Herbivore-induced plant volatiles (HIPVs), alarm pheromones like (E) β farnesene, honeydew volatiles, and contact cues enhance biological control by improving host-search efficiency and parasitism rates through tritrophic signaling. However, semiochemicals may also disrupt biological control via signal masking, repellent allomones, reduced host quality, or attraction of hyperparasitoids. Environmental changes, including elevated CO₂ and temperature, can further modify volatile emissions and impair cue reliability. Behavioral plasticity, olfactory processing, and associative learning in natural enemies determine their responses to semiochemical blends. Understanding both positive and negative effects of semiochemicals is therefore essential for optimizing their application in sustainable integrated pest management programs.

Introduction

Semiochemicals are substances or mixtures of substances released from one organism that evokes either a behavioral or physiological response between members of the same or different species. These compounds belong to diverse chemical groups such as aldehydes, alcohols, terpenes, esters, sulfur compounds, proteins, amino acids, and others. Because of their diversity, semiochemicals influence complex interactions among insect pests and biological control agents (BCAs). Research on semiochemical BCA interactions is expanding due to their potential to enhance sustainable pest management and reduce reliance on conventional pesticides. Semiochemicals are crucial in the biological control

of arthropods, as they facilitate chemical interactions between plants, insect pests, parasitoids, and predators and are utilized in integrated pest management (IPM) (Sharma *et al.*, 2019). In agricultural ecosystems, semiochemicals play a crucial role in managing interactions among plants, herbivores, and their natural enemies across three trophic levels. Herbivore-induced plant volatiles (HIPVs) serve as indirect defense mechanisms by luring parasitoids and predators to areas where herbivores are feeding (Guo and Wang, 2025). Kairomones produced by herbivores, like the aphid alarm pheromone (E)- β -farnesene, improve biological control by drawing in *Aphidius* parasitoids and hoverflies (Qin *et al.*, 2022). Furthermore, volatiles from honeydew and

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waste products from hosts act as attractants and stimulate oviposition (Leroy *et al.*, 2011). However, semio-chemicals can also interfere with biological control efforts. Volatiles from non-host plants might obscure host signals, diminishing the effectiveness of parasitoids (Sharma *et al.*, 2019), while plant-mediated defenses could reduce prey quality or attract hyperparasitoids and intraguild predators (Pappas *et al.*, 2017). Therefore, comprehending the dual nature of semiochemicals is vital for successful integrated pest management.

Semiochemical Types & Roles: The categorization of these semiochemicals is illustrated in the Fig. 1. Semiochemicals are chemical signals that mediate interactions among organisms. Pheromones act between members of the same species and include Aggregation pheromone (attracts both sexes to food or breeding sites), Alarm pheromone (warns conspecifics of danger), Oviposition-deterrent pheromone (prevents other females from laying eggs in the same resource), Home/Queen recognition pheromone (enables colony members to recognize and attend their queen or nest), Sex pheromone (attracts opposite sex for mating), Trail pheromone (guides nestmates to food or resources), Recruitment pheromone (mobilizes nestmates to a work or resource site), Royal pheromone (signals royal status and regulates worker recognition/behavior), while allelochemicals act between different species and include allomones (benefit the emitter), kairomones (benefit the receiver), synomones (benefit both), Antimones (maladaptive for both the releaser and

receiver) and apneumones (released from abiotic sources benefiting the receiver).

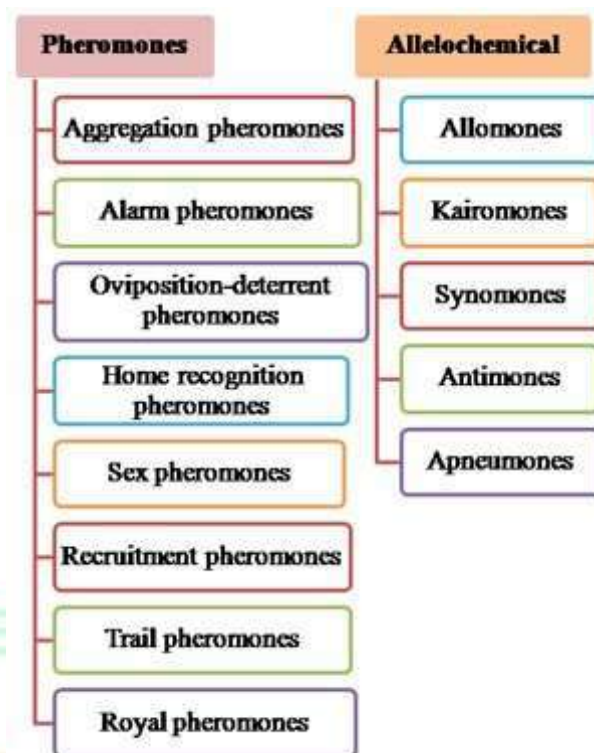


Fig. 1: Classification of Semiochemicals; Categorized into two types (a) Phromones, (b) Allelochemicals (El-Ghany, 2019).

Types of Semiochemical Effects on Natural Enemies

Direct Positive Effects

Attraction and Host/Prey Location: Semiochemicals play a crucial role in enhancing the efficiency of host and prey location for parasitoids and predators. Herbivore-induced plant volatiles (HIPVs), insect pheromones, frass volatiles, and cuticular hydrocarbons serve as orientation signals that direct natural enemies to plants under attack. Recent research indicates that parasitoids can distinguish between the volatile mixtures released by infested and non-infested plants, thereby increasing their foraging precision in natural settings (Turlings

and Erb, 2018; Gebreziher, 2018; Saravanan *et al.*, 2025). The aphid alarm pheromone (E)- β -farnesene has been shown to attract parasitoids like *Aphidius ervi* and syrphid predators, leading to greater aggregation of natural enemies and enhanced pest control (Wang *et al.*, 2022; Qin *et al.*, 2022). These reactions improve the effectiveness of biological control by decreasing search time and boosting encounter rates.

Oviposition Stimulation and Retention: Semiochemicals also affect behaviors following attraction, such as the acceptance of hosts and the laying of eggs. Contact kairomones found on host surfaces trigger egg-laying behavior in egg and larval parasitoids (El-Shafie and Faleiro, 2017; Sharma *et al.*, 2019). Additionally, volatiles linked to honeydew and floral fragrances boost the longevity, reproductive capacity, and retention of parasitoids in the field, which results in higher parasitism rates (Wäckers *et al.*, 2008; You *et al.*, 2024; Tena *et al.*, 2016). Field experiments show that integrating sugar resources with HIPVs greatly enhances the establishment of parasitoids and the effectiveness of biological control (Hyder *et al.*, 2025).

Indirect Positive Effects

Tritrophic Signaling and Indirect Plant Defense:

Semiochemicals play a crucial role in indirect plant defense by facilitating tritrophic interactions. When plants are attacked by herbivores, pathways regulated by jasmonic acid are activated, resulting in the release of herbivore-induced plant volatiles (HIPVs) that lure natural predators.

Recent transcriptomic and metabolomic studies have shown that these volatile mixtures are highly specific to the type of herbivore and their feeding behavior (Mitra and Barik, 2024). This specificity enhances the reliability of the signals and aids parasitoids in distinguishing between different threats in complex ecological settings (Poelman *et al.*, 2012; McCormick *et al.*, 2017). This form of chemically mediated indirect defense is now acknowledged as a fundamental mechanism in ecological pest control.

Landscape-Level Habitat Effects: Semiochemicals play a role in altering the distribution of natural predators throughout agricultural areas. Strategies that diversify habitats and increase the variety of volatiles can enhance the recruitment of natural enemies and improve pest control on a landscape scale (Turlings and Erb, 2018). Recent studies on ecological networks indicate that semiochemical signals function within community-level interaction webs, boosting ecosystem resilience when effectively managed (McCormick *et al.*, 2017).

Direct Negative Effects

Chemical Interference and Signal Masking:

Semiochemicals can diminish the effectiveness of natural enemies when signals become unreliable or obscured. In diverse cropping systems, background plant volatiles may dilute or disrupt host-specific cues, resulting in decreased attraction of parasitoids (Liu *et al.*, 2019; Sharma *et al.*, 2019). Experimental findings indicate that the blending of volatiles from nearby non-host plants can significantly impair the accuracy of parasitoid orientation, leading to lower

parasitism rates in complex field environments (Ponzio *et al.*, 2016; Kruidhof *et al.*, 2015).

Repellent Allomones and Herbivore Counter-Adaptations: Herbivores may be able to defend themselves from parasitoid predators by producing semiochemical signals that either repel them or interfere with the ability of parasitoids to find host plants. Some plant responses after egg-laying can also result in decreased attraction of parasitoids (Fatouros *et al.*, 2020). Some of the secondary metabolites produced by plants may function as allomones, thereby reducing predation on herbivores (Divekar *et al.*, 2022). The development of these defensive adaptations is an example of evolutionary strategies introduced by herbivore noseata (use of plant semiochemical signals to attract parasitoid predators) and that limit the effectiveness of biological pest control through semiochemical mechanisms.

Indirect Negative Effects

Reduced Host Quality: Herbivory induced plant defenses can result in a decrease in nutritional quality of the herbivore. While this is advantageous to the plant, the size or chemical characteristics of a host that are smaller or altered can have negative impacts on parasitoids (Divekar *et al.*, 2022; Ataide *et al.*, 2016). The long term biological control efficiency may be less due to the indirect effects from herbivory reduced herbivore density in the short term.

Attraction of Hyperparasitoids: Hyperparasitoids, which parasitize the primary parasitoid, can negatively impact biological control when they are

attracted by semiochemicals released from herbivores that have been parasitized, or plants that are infected by those herbivores (Poelman *et al.*, 2012; Cusumano *et al.*, 2020). Hyperparasitoids can also use herbivore-induced plant volatiles (HIPVs) to find their parasitoid hosts in the field, which has potential ramifications for stability in biological control programs (Cusumano *et al.*, 2020).

Climate and Environmental Disruption: Changes in the climate can have an effect on the rate, chemistry, and dispersion characteristics of volatile emissions. Changes in temperature and elevated levels of CO₂ may alter the composition of HIPV blends, reducing the ability of parasitoids to locate their hosts and disrupting mutual synchrony of species (Daussy and Staudt, 2020; Lupitu *et al.*, 2022). This will increase the threat of altering biological control methods using semiochemicals as a basis for implementing these techniques in the long term.

Table 1: Effect of Semiochemical on Neutral enemies

Effect Category	Direction	Impact
Host attraction	Positive	Enhanced parasitism/predation
Oviposition stimulation	Positive	Increased reproductive output
Tritrophic signaling	Positive	Improved indirect plant defense
Signal masking	Negative	Reduced host-finding accuracy
Allomones	Negative	Repellent/deterrent effects
Host quality reduction	Indirect negative	Lower parasitoid fitness
Hyperparasitoid recruitment	Indirect negative	Reduced biological control
Climate disruption	Indirect negative	Signal unreliability

Mechanisms Underlying Semiochemical Effects

on Natural Enemies

Behavioral and Neurological Processes in Natural

Enemies: Semiochemicals regulate natural enemies by shaping foraging, host recognition, orientation, and decision-making via olfactory systems. Antennal receptors detect volatile cues, which are processed in neural centers (antennal lobe and mushroom bodies) to produce specific behavioural responses, enabling discrimination of host, plant, and environmental odors (Laumann *et al.*, 2026; González *et al.*, 2018). Parasitoids show species-specific adaptation to host-associated kairomones and HIPVs, with olfactometer assays confirming selective responses to relevant odors (González *et al.*, 2018). Herbivore-induced plant volatiles enhance predator and parasitoid attraction, strengthening tritrophic communication and biological control (Tamiru and Khan, 2017). Neural plasticity mediated by octopamine further refines odor-reward learning and adaptive behavioral responses (Delahunt *et al.*, 2018).

Learning and Memory in Parasitoid Responses to

Semiochemicals: Parasitoids exhibit associative learning, modifying odor responses based on successful host encounters to improve host-finding efficiency (Peri *et al.*, 2016). *Trichogramma* spp. show both innate and learned olfactory responses, refining preferences toward reliable host-associated cues and adapting to variable plant volatiles (Wilson and Woods, 2016). They can also learn synthetic or induced semiochemical blends, enhancing attraction to egg-infested plants and improving biological control potential (Ali and Wright, 2021).

However, learning may cause biases if cues become unreliable, reflecting a balance between innate and experience-based responses (Laumann *et al.*, 2026).

Challenges and Knowledge Gaps

Field Variability

- ✓ Lab attraction $\neq$ consistent field performance
- ✓ Wind, temperature, and background odors reduce signal strength
- ✓ HIPVs may dissipate or be masked in complex landscapes
- ✓ Habitat complexity alters natural enemy response

Signal Reliability & Ecological Traps

- ✓ Semiochemicals effective only when host presence is reliable
- ✓ Synthetic lures may attract natural enemies to low-prey areas
- ✓ Risk of energy loss and reduced biocontrol efficiency
- ✓ HIPVs sometimes emitted without actual herbivore presence

Multi-Species Interactions

- ✓ Most studies focus on single pest enemy systems
- ✓ Volatiles may attract non-targets or hyper-parasitoids
- ✓ Possible disruption of trophic cascades
- ✓ Community-level responses remain under-explored

Future Research Directions

AI-Assisted Chemical Ecology

- ✓ Machine learning to predict optimal volatile blends
- ✓ Modeling tritrophic interactions

- ✓ Precision-based semiochemical deployment

Microbiome Semiochemical Interactions

- ✓ Microbes influence plant volatile production
- ✓ Symbionts modify herbivore odor profiles
- ✓ Impacts parasitoid/predator attraction
- ✓ Promising area for improving biocontrol reliability.

Conclusion

Semiochemicals exert both beneficial and detrimental effects on natural enemies, shaping multitrophic interactions in agricultural ecosystems. While herbivore-induced plant volatiles, pheromones, and kairomones enhance host location, oviposition, and biological control efficiency, signal interference, hyperparasitoid attraction, and climate-driven disruptions can limit their effectiveness. The behavioral plasticity and learning ability of parasitoids and predators further influence these outcomes. Therefore, a balanced and ecologically informed use of semiochemicals is crucial for strengthening sustainable integrated pest management strategies.

References

- Ali, A. N. and Wright, M. G. (2021). Response of *Trichogramma papilionis* to semiochemicals induced by host oviposition on plants. *Biological Control*, 154: 104510.
- Divekar, P. A., Narayana, S., ... and Behera, T. K. (2022). Plant Secondary Metabolites as Defense Tools against Herbivores for Sustainable Crop Protection. *International Journal of Molecular Sciences*, 23(5): 2690.
- Ataide, L. M., Pappas, M. L., Schimmel, B. C., Lopez-Orenes, A., Alba, J. M., Duarte, M. V. and Kant, M. R. (2016). Induced plant-defenses suppress herbivore reproduction but also constrain predation of their offspring. *Plant Science*, 252: 300-310.
- Cusumano, A., Harvey, J. A., Bourne, M. E., Poelman, E. H. and G de Boer, J. (2020). Exploiting chemical ecology to manage hyperparasitoids in biological control of arthropod pests. *Pest Management Science*, 76(2): 432-443.
- Daussy, J. and Staudt, M. (2020). Do future climate conditions change volatile organic compound emissions from *Artemisia annua*? Elevated CO₂ and temperature modulate actual VOC emission rate but not its emission capacity. *Atmospheric Environment: X*, 7, 100082.
- Delahunt, C. B., Riffell, J. A. and Kutz, J. N. (2018). Biological mechanisms for learning: a computational model of olfactory learning in the *Manduca sexta* moth, with applications to neural nets. *Frontiers in Computational Neuroscience*, 12: 102.
- El-Ghany, N. M. A. (2019). Semiochemicals for controlling insect pests. *Journal of Plant Protection Research*, 59(1).
- Peri, E., Salerno, G., Slimani, T., Frati, F., Conti, E., Colazza, S. and Cusumano, A. (2016). The response of an egg parasitoid to substrate-borne semiochemicals is affected by previous experience. *Scientific Reports*, 6(1): 27098.

- El-Shafie, H. A. F. and Faleiro, J. R. (2017). Semiochemicals and their potential use in pest management. In Biological control of pest and vector insects. *IntechOpen*.
- Fatouros, N. E., Cusumano, A., Bin, F., Polaszek, A. and Van Lenteren, J. C. (2020). How to escape from insect egg parasitoids: a review of potential factors explaining parasitoid absence across the Insecta. *Proceedings of the Royal Society B: Biological Sciences*, 287(1931).
- Gebreziher, H. G. (2018). The role of herbivore-induced plant volatiles (HIPVs) as indirect plant defense mechanism in a diverse plant and herbivore species; a review. *International Journal of Agriculture Environment and Food Sciences*, 2(4): 139-147.
- González, J. M., Camino, D., Simon, S. and Cusumano, A. (2018). Semiochemical exploitation of host-associated cues by seven *Melittobia* parasitoid species: behavioral and phylogenetic implications. *Frontiers in Ecology and Evolution*, 5 172.
- Guo, H. and Wang, C. Z. (2025). Harnessing semiochemicals for parasitoid-based biological control: from laboratory identification to field applications. *Crop Health*, 3: 21.
- Turlings, T. C. and Erb, M. (2018). Tritrophic interactions mediated by herbivore-induced plant volatiles: mechanisms, ecological relevance, and application potential. *Annual Review of Entomology*, 63: 433-452.
- Hyder, M., Ul Haq, I., Younas, M., Ghafar, M. A., Akhtar, M. R., Ahmed, Z., Bukero, A. and Hou, Y. (2025). Floral Resource Integration: Enhancing Biocontrol of *Tuta absoluta* Within Sustainable IPM Frameworks. *Plants*, 14(3): 319.
- Kruidhof, H. M., Roberts, A. L., Magdaraog, P., Muñoz, D., Gols, R., Vet, L. E., Hoffmeister, T. S. and Harvey, J. A. (2015). Habitat complexity reduces parasitoid foraging efficiency, but does not prevent orientation towards learned host plant odours. *Oecologia* 179(2): 353-361.
- Laumann, R. A., Michereff, M. F. F., de Aquino, M. F. S., Borges, M. and Blassioli-Moraes, M. C. (2026). Semiochemicals for management of natural enemies. In Behavior of Insect Natural Enemies (pp. 223-237). Academic Press. <https://doi.org/10.1016/B978-0-443-24796-5.00024-1>.
- Leroy, P. D., Sabri, A., Heuskin, S., Thonart, P., Lognay, G., Verheggen, F. J. and Haubruge, E. (2011). Microorganisms from aphid honeydew attract and enhance the efficacy of natural enemies. *Nature Communications*, 2(1): 348.
- Liu, C. M., Matsuyama, S. and Kainoh, Y. (2019). Synergistic effects of volatiles from host-infested plants on host-searching behavior in the parasitoid wasp *Lytopylus rufipes* (Hymenoptera: Braconidae). *Journal of Chemical Ecology*, 45(8): 684-692.

- Lupitu, A., Moisa, C., Gavrilas, S., Dochia, M., Chambre, D., Ciutină, V., Copolovici, D. M. and Copolovici, L. (2022). The Influence of Elevated CO₂ on Volatile Emissions, Photosynthetic Characteristics, and Pigment Content in Brassicaceae Plants Species and Varieties. *Plants (Basel, Switzerland)*, 11(7): 973.
- McCormick, A. C., Heyer, J., Sims, J. W., Mescher, M. C. and De Moraes, C. M. (2017). Exploring the effects of plant odors, from tree species of differing host quality, on the response of *Lymantria dispar* males to female sex pheromones. *Journal of Chemical Ecology*, 43(3): 243-253.
- Mitra, S. and Barik, A. (2024). The Chemical Language of Plant Defense: Volatile Organic Compounds (VOCs) and Tritrophic Interactions. *Journal of Applied Bioscience*, 50 (2): 63-72.
- Pappas, M. L., Broekgaarden, C., Broufas, G. D., Kant, M. R., Messelink, G. J., Steppuhn, A., Wäckers, F., and van Dam, N. M. (2017). Induced plant defences in biological control of arthropod pests: a double-edged sword. *Pest Management Science*, 73(9): 1780-1788.
- Poelman, E. H., Bruinsma, M., Zhu, F., Weldegergis, B. T., Boursault, A. E., Jongema, Y. and Dicke, M. (2012). Hyperparasitoids use herbivore-induced plant volatiles to locate their parasitoid host. *PLoS Biology*, 10(11).
- Ponzio, C., Cascone, P., Cusumano, A., Weldegergis, B. T., Fatouros, N. E., Guerrieri, E. and Gols, R. (2016). Volatile-mediated foraging behaviour of three parasitoid species under conditions of dual insect herbivore attack. *Animal Behaviour*, 111: 197-206.
- Qin, Y., Zhang, S. and Li, Z. (2022). Kairomonal Effect of Aphid Alarm Pheromones and Analogs on the Parasitoid *Diaeretiella rapae*. *Insects*, 13(11): 1055.
- Saravanan, S., Shanmugam, P. S., Subaharan, K., Murugan, M., Srinivasan, T., Elaiyabharathi, T. and Alagar, M. (2025). Unlocking the potential of semiochemicals: A comprehensive review of their current developments and future prospects in sustainable pest management. *Journal of Environmental Biology*, 46(6): 773-782.
- Sharma, A., Sandhi, R. K. and Reddy, G. V. P. (2019). A Review of Interactions between Insect Biological Control Agents and Semiochemicals. *Insects*, 10(12): 439.
- Tamiru, A. and Khan, Z. R. (2017). Volatile Semiochemical Mediated Plant Defense in Cereals: A Novel Strategy for Crop Protection. *Agronomy*, 7(3): 58.
- Tena, A., Wäckers, F. L., Heimpel, G. E., Urbaneja, A. and Pekas, A. (2016). Parasitoid nutritional ecology in a community context: the importance of honeydew and implications for biological control. *Current Opinion in Insect Science*, 14: 100-104.

Integrating Phytobiotics in Shrimp Culture: A Green Alternative to Antibiotics

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Abstract

Aquaculture relies heavily on the production of marine shrimp, primarily *Penaeus monodon* and *Litopenaeus vannamei*. Growing marine shrimp contributes to the production of human protein, creates jobs, and brings in large sums of money for investors. The development of marine shrimp farming may be hampered by intensification farming methods that cause poor water quality, stress, and starvation in the farmed shrimp, which can lead to disease outbreaks and low productivity. In shrimp farming, antibiotics are frequently used as a temporary remedy for illnesses. Furthermore, consumer trust in aqua-products is damaged by the detrimental effects of antibiotic use on the environment and public health. Phytobiotic research as a preventative measure in aquaculture has gained a lot of attention more recently. The positive benefits of different phytobiotics on aquaculture species have been investigated. This article summarizes the sources of phytobiotics, their mechanisms, and their role in shrimp production, including boosting growth performance, antioxidant capacity, immune system enhancement, disease resistance, and resilience to abiotic stress.

Introduction

Aquaculture is the fastest-growing food production sector, contributing nearly half of the global fish supply. Crustaceans like whiteleg shrimp (*Litopenaeus vannamei*), black tiger shrimp (*Penaeus monodon*), and crabs are highly valued worldwide. Their rapid growth, nutritional value, and profitability attract significant investment. Shrimp farming, primarily in tropical regions, generates billions in annual revenue for countries in Latin America and Asia. *P. monodon* is the second most farmed shrimp globally, with 4200 MT produced in 2019 and a market value of USD 4.8 billion, employ-

ing around 1.2 million people. In 2016, global production of *P. monodon* and *L. vannamei* reached nearly 5 million tons. *L. vannamei* has become dominant due to its resilience, fast growth, and high yield, comprising over 51% of marine shrimp production in 2020 with 5.81 million tons (Wei *et al.*, 2024). Its low feed conversion ratio and adaptability make it a top aquaculture choice. Overall, marine shrimp farming offers high returns, employment, and nutritious seafood products. High-density crustacean farming leads to stress and poor water quality, causing disease outbreaks, mortality, and economic loss. As the industry intensifies, disease remains a

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major barrier to growth. Common infections include vibriosis, white spot syndrome virus (WSSV) disease, early mortality syndrome (EMS) or acute hepatopancreatic necrosis disease (AHPND), yellow head virus (YHV) disease, gill-associated virus (GAV) disease, infectious hypodermal and hematopoietic necrosis virus (IHHNV) disease, and microsporidiosis caused by *Enterocytozoon hepatopenaei*, with some causing severe early-stage mortality. While antibiotics have been widely used, their overuse poses health and environmental risks (Vaiyapuri *et al.*, 2021). As alternatives, probiotics, prebiotics, symbiotics, vaccines, and phytobiotics are gaining attention. Phytobiotics are affordable, accessible, and effective, like chamomile oil improves growth, antioxidant activity, and disease resistance in *P. indicus*. Many studies have revealed the potential of phytobiotics in shrimp farming. For example, chamomile oil, used as a feed additive in *P. indicus* farming, can elevate growth performance, increase antioxidant capacity, and stimulate disease resistance to *V. parahaemolyticus*.

Phytobiotics: sources, mode of action

Phytobiotics encompass a wide range of plant-based materials, including herbs, fruits, vegetables, seaweeds, mushrooms, and agricultural by-products like fruit waste and rice bran. They also contain bioactive compounds such as tannins, alkaloids, saponins, essential oils, flavonoids, and polysaccharides, which provide antimicrobial, antioxidant, anti-inflammatory and immunostimulant effects. Widely studied across species, phyto-

biotics are known to enhance growth, immunity, antioxidant levels, gut microbiota balance, and stress resistance in aquatic animals. They promote beneficial gut bacteria like *Lactobacilli* and *Bifidobacteria*, supporting immune function and defending against pathogens (Fig. 1).

Phytobiotics vs Growth performance

Microalgae are key live feeds in aquaculture, rich in protein, polyunsaturated fatty acids (PUFAs), vitamins, pigments, and sterols. They support growth, stress relief, disease resistance, and flesh quality in aquatic species. Similarly, macroalgae (seaweeds) like *Carpoblepharis flaccida*, *Ecklonia maxima*, *Gracilaria gracilis*, *Laminaria japonica*, and *Ulva* spp. have shown beneficial effects as feed additives (Wei *et al.*, 2024). Seaweeds used in crustacean farming, such as *G. tenuitipitata*, *G. fisheri*, and *Jania adherens*, contain essential fatty acids, amino acids, minerals, vitamins, and bioactive compounds. These contribute to improved growth, feed efficiency, immunity, and flesh quality. Their abundance and low cost make seaweeds attractive for aquafeed formulations. Polyculture of macroalgae and shrimp offers mutual benefits. For instance, co-culturing *Caulerpa lentillifera* (sea grapes) with *L. vannamei* enhances the growth of both species. Native to tropical seas and widely farmed in countries like China, Vietnam, the Philippines, Taiwan, and Japan, sea grapes, also known as green caviar, are valued for their nutritional and health-promoting properties. Additionally, their high nutrient uptake capacity makes them effective in

treating aquaculture, industrial, and heavy metal-contaminated wastewater.

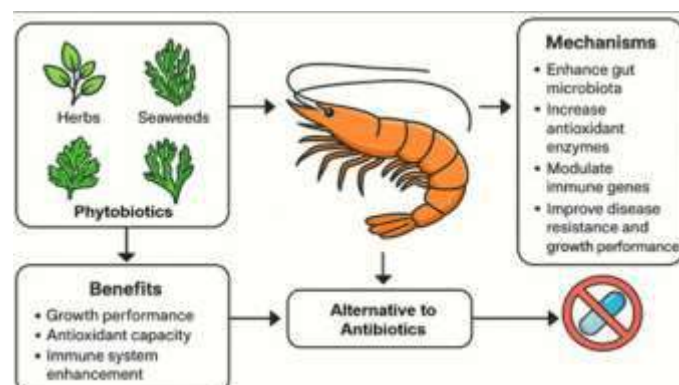


Fig 1: Sources and role of phytobiotics in aquaculture

Phytobiotics as immunostimulants

Medicinal plants are widely used as immunostimulants in aquaculture, improving growth, immunity, stress tolerance, and disease resistance (Prabu *et al.*, 2018). Herbs like *Andrographis paniculata*, *Allium sativum*, and *Petalonia binghamiae* have shown efficacy against pathogens in *P. monodon* and *L. vannamei* (Citarasu *et al.*, 2006). Other promising herbs include *Eclipta erecta*, *Agati grandiflora*, *Justicia tranquebariensis*, and *Cynodon dactylon*. Their effects are largely attributed to bioactive compounds such as polyphenols, alkaloids, flavonoids, and essential oils, which also promote gut health and metabolism (Corry *et al.*, 2018). Plants like *Forsythia suspensa*, rich in glycosides and lignans, enhance immunity in *P. monodon*, while *Syzygium cumini* and *Moringa oleifera* provide antimicrobial, antioxidant, and feed-attractant benefits. These have been used in shrimp, tilapia, carp, and trout to improve health and performance. *Salvinia cucullata* has shown efficacy against *Vibrio parahaemolyticus* in *L. vannamei* due

to its diverse phytochemicals. Red seaweeds like *Sarcodia suae* and *Jania adhaerens* enhance disease resistance in *L. vannamei* and tilapia via compounds like acetyl-xylogalactan and tannins. While Chinese herbs such as *Siwu decoction* offer anti-inflammatory benefits, fermentation is used to reduce potential toxicity and enhance bioactivity. Finally, β -glucans, especially from *Saccharomyces cerevisiae*, are proven immunostimulants that improve growth and resistance to pathogens like WSSV in *P. monodon* and *P. merguensis* (Pooljun *et al.*, 2022).

Phytobiotics vs Abiotic stressors

Tannic acid, a plant-derived compound, benefits various aquatic species by enhancing their immunity and antioxidant capacity. In *L. vannamei*, it alleviates ammonia-induced stress, and as a feed additive, it improves growth, immunity, and disease resistance in mussels (*Unio tumidus*), grass carp, zebrafish, and Nile tilapia (Gong *et al.*, 2022). It also supports health and growth in livestock like chickens and piglets (Starčević *et al.*, 2015). Similarly, β -glucan enhances immunity and antioxidant defenses in *L. vannamei* under low salinity stress (Qiao *et al.*, 2022) and reduces stress in Golden pompano (*Trachinotus ovatus*) (Do Huu *et al.*, 2016). Due to its cost-effectiveness and availability, β -glucan is a valuable additive in marine shrimp farming.

Conclusion

Shrimp farming is economically vital in many tropical and subtropical regions but faces setbacks due to frequent disease outbreaks.

While antibiotics have been effective, concerns over public health and environmental impact limit their use. Phytobiotics offer a sustainable alternative, being affordable, abundant, and environmentally friendly. Several commercial phytobiotics such as tannic acid, Polygain™ (PRSE), Wakame (*U. pinnatifida*), AquaImmu, β -glucan, and sea grape (*C. lentillifera*), are suitable for large-scale application. As practical feed additives, phytobiotics support immune health and disease resistance, though improper dosing may impair shrimp performance. Understanding the underlying molecular and cellular immune mechanisms is essential to optimize their use in combating pathogens and stressors.

References

- Citarasu, T., Sivaram, V., Immanuel, G., Rout, N. and Murugan, V. (2006). Influence of selected Indian immunostimulant herbs against white spot syndrome virus (WSSV) infection in black tiger shrimp, *Penaeus monodon* with reference to haematological, biochemical and immunological changes. *Fish & Shellfish Immunology*, 21(4): 372-384.
- Cory, H., Passarelli, S., Szeto, J., Tamez, M. and Mattei, J. (2018). The role of polyphenols in human health and food systems: A mini-review. *Frontiers in Nutrition*, 5: 370438.
- Do Huu, H., Sang, H. M. and Thuy, N. T. T. (2016). Dietary β -glucan improved growth performance, *Vibrio* counts, haematological parameters and stress resistance of pompano fish, *Trachinotus ovatus* Linnaeus, 1758. *Fish & Shellfish Immunology*, 54: 402-410.
- Gong, H., Qin, Z., Chen, Z., Li, J., Chang, Z., Li, J. and Chen, P. (2022). Effects of dietary tannic acid on growth, digestion, immunity and resistance to ammonia stress, and intestinal microbial community in Pacific white shrimp (*Litopenaeus vannamei*). *Fishes*, 7(6): 327.
- Pooljun, C., Jariyapong, P., Wongtawan, T., Hirono, I. and Wuthisuthimethavee, S. (2022). Effect of feeding different types of β -glucans derived from two marine diatoms (*Chaetoceros muelleri* and *Thalassiosira weissflogii*) on growth performance and immunity of banana shrimp (*Penaeus merguensis*). *Fish & Shellfish Immunology*, 130: 512-519.
- Prabu, D. L., Chandrasekar, S., Ambashankar, K., Dayal, J. S., Ebeneezar, S., Ramachandran, K., Kavitha, M. and Vijayagopal, P. (2018). Effect of dietary *Syzygium cumini* leaf powder on growth and non-specific immunity of *Litopenaeus vannamei* (Boone 1931) and defense against virulent strain of *Vibrio parahaemolyticus*. *Aquaculture*, 489: 9-20.
- Qiao, Y., Zhou, L., Qu, Y., Lu, K., Han, F. and Li, E. (2022). Effects of different dietary β -glucan levels on antioxidant capacity and immunity, gut microbiota and transcriptome responses of white shrimp (*Litopenaeus vannamei*) under low salinity. *Antioxidants*, 11(11): 2282.
- Starčević, K., Krstulović, L., Brozić, D., Maurić, M.,

Stojević, Z., Mikulec, Ž., Bajić, M. and Mašek, T. (2015). Production performance, meat composition and oxidative susceptibility in broiler chicken fed with different phenolic compounds. *Journal of the Science of Food and Agriculture*, 95(6): 1172-1178.

Vaiyapuri, M., Pailla, S., Rao Badireddy, M., Pillai, D., Chandragiri Nagarajarao, R. and Prasad Mothadaka, M. (2021). Antimicrobial resistance in Vibrios of shrimp aquaculture: Incidence, identification schemes, drivers and mitigation measures. *Aquaculture Research*, 52(7): 2923-2941.

Wei, L. S., Sukri, S. A. M., Tahiluddin, A. B., Kari, Z. A., Wee, W. and Kabir, M. A. (2024). Exploring beneficial effects of phytobiotics in marine shrimp farming: A review. *Heliyon*.

Artificial Intelligence in Seed Quality Assessment: From Lab to Field

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Abstract

Innovations based on artificial intelligence (AI) technology have been changing the scenario of seed quality analysis for next-generation applications. These innovations aim to overcome the drawbacks of traditional manual inspection methods for seed quality analysis, which is time-consuming and results in inconsistencies between different testing laboratories. This review aims to discuss various AI-based strategies for seed quality analysis, including non-destructive techniques like remote sensing, NIR spectroscopy, X-ray imaging, hyperspectral imaging, multispectral imaging, and electronic noses.

Introduction

Increased global food demand in the face of climate change challenges exacerbates the pressure on food production systems, where high-quality seeds are a key factor in maximizing productivity (Chowdhury, 2023). In conventional laboratory-based seed testing, purity, vigour, and absence of contaminants are emphasized, though these methods are often characterized by delays, subjectivity, and destruction of seeds (Kameswara *et al.*, 2017). Artificial intelligence-based solutions facilitate these processes, minimizing human error due to long testing durations (Boucek *et al.*, 2007). With advances in sensing technology, IoT, and computing, site-specific testing of individual seeds for characteristics like vigour and damage can be conducted accurately. This development resonates with the appeal for fast and non-destructive testing methods as advocated by ISTA and AOSA. Bibliographic trends show a surging research focus on the utilisation of AI in seed

quality assessment.

Artificial Intelligence in Seed Quality Assessment

Remote Sensing: Remote sensing is a data acquisition process that utilizes satellites or drones, where data is collected without any physical contact with the crop or seed, analyzing the reflected data to obtain crop and seed-related data. It analyzes the spectrum and texture of the crop or seed for differentiation and forecasting crop yield (Zhang *et al.*, 2020; Ren *et al.*, 2020).

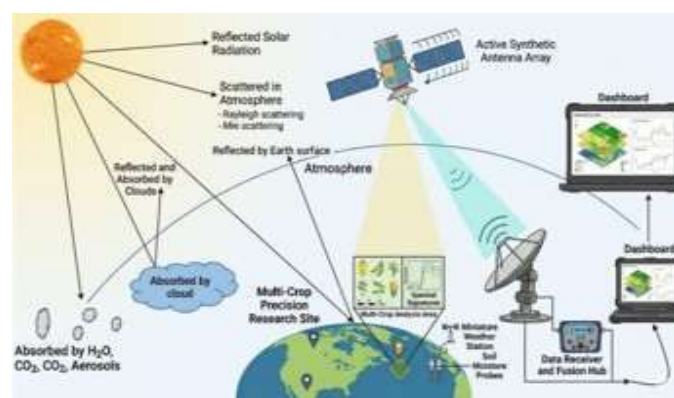


Fig. 1: Remote Sensing in seed assessment

Some of the notable uses of this method include the sizing of crops through millimeter wave

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radar, which is not influenced by dust, and the mapping of protein concentration for zoning of the harvest (Nuttall *et al.*, 2024; Bakumenko *et al.*, 2021). Associating remote sensing with machine learning can be used for consistency in grading (Raj and Swaminarayan, 2015). It is also used for yield gap analysis, where seed quality is correlated with environmental factors (Beza, 2017).

Near-Infrared (NIR) Spectroscopy: Near-Infrared Spectroscopy, which involves the range of 780 to 2500 nm, identifies the presence of chemical bonds in seeds via absorption and scattering, allowing the evaluation of moisture, proteins, and lipids without damaging the seeds. The FT-NIR method for seed vigor classification has achieved 91 to 100% accuracy in soybean (Qiu *et al.*, 2018). It also predicts the percentage of hard seeds and moisture in corn and cacao (Ling-ling, 2015; Priambodo *et al.*, 2022).

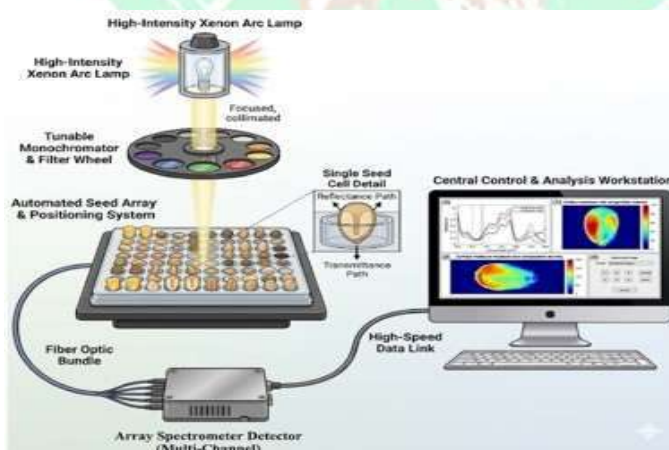


Fig. 2: NIR Spectroscopy

Chemometrics, including the use of Partial Least Squares Discriminant Analysis (PLS-DA), has also improved the method of seed classification (Pandiselvam *et al.*, 2022). The problem caused by

spectral noise can be tackled by preprocessing aided by AI integration.

X-ray imaging: X-ray computed tomography (CT) with a wavelength range of 0.01-10 nm is used for imaging seeds. This method is used for the generation of two-dimensional and three-dimensional images of seeds. Soft X-ray imaging is used for the detection of embryo voids, which is responsible for low germination in Brassicaceae (Musaev *et al.*, 2022). This method is also used for the detection of mechanical damage and insect infestation without damaging the sample (Chavagnat, 1987). This method, when combined with color imaging, is used for the assessment of seed viability along with morphology (Masry *et al.*, 2019).

Hyperspectral Imaging (HSI): The technique of Hyperspectral Imaging involves the use of both spectroscopy and imaging to create a three-dimensional hypercube (400-2500 nm). It is used for mapping the distribution of chemicals. Push-broom sensors are used to scale from laboratory to industrial uses (ElMasry *et al.*, 2007). It is used to predict kernel viability and outperforms single-point NIR (Xia *et al.*, 2019).

Multispectral Imaging (MSI): This technique collects data from a range of selected wavelengths, i.e., ten bands, which reduces the data size for faster processing. It has the capability to detect coated cultivars with an accuracy rate of 93% for legumes. It is also useful for the detection of fungi even when they are coated (Michelon *et al.*, 2023; Jia *et al.*, 2022). It has applications in the assessment of matur-

ity in beets and dormancy through omics (Mortensen *et al.*, 2021; Wang *et al.*, 2023), along with the integrated use of colour MSI for the complete quantification of traits.

Electronic Nose (e-Nose): Electronic noses use sensor arrays to detect volatile organic compounds (VOCs), producing an aroma signature related to storage damage and fungal decay (e.g., *Aspergillus* spp. volatiles for grains) (Gancarz *et al.*, 2017). They can detect the aging of rice and rapeseed by using pattern recognition (Xu *et al.*, 2021).

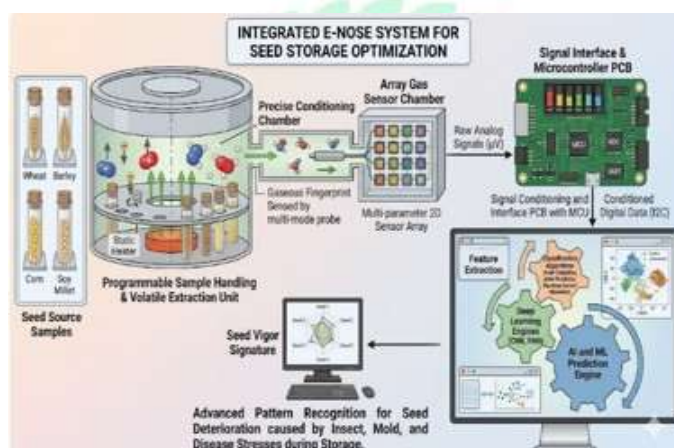


Fig. 3: Electronic Nose (e-Nose)

Challenges faced in utilization of AI based technology

Despite several upsides, the utilization of AI in seed quality assessment is limited by a few hurdles. The need for crop-specific calibrations and large data sets is a problem for NIR/HSI. Environmental noise can also mess around with predictions (Xia *et al.*, 2019). X-ray is a problem because it limits throughput and inference of viability. Getting it off the ground is difficult because of cost, training people, privacy issues from drones/AI, and data overwhelm, which needs filtering (Dinkar *et al.*,

2024). Real-time systems need expert input for accuracy (Washington and Roth, 1989). Flexible, internet-proof systems are required for remote farming.

Conclusion and Future Prospects

AI tools are transforming seed testing from destructive to efficient and accurate practices, ensuring farmers receive viable seeds. The surge in AI-based research necessitates the need for future directions, including species models, portable devices, and the relationship between spectral and trait information. Validation will be crucial to ensure the successful deployment of these tools, which will enhance productivity despite food security issues.

References

- Bakumenko, D., Nuttall, J. and Perry, E. (2021). Remote sensing for protein concentration mapping in grains. *Remote Sensing of Environment*, 262: 112-125.
- Beza, E., Boogaard, H. and van der Velde, M. (2017). Yield gap analysis using remote sensing. *Field Crops Research*, 212: 1-12.
- Boucek, C., Dehais, F. and Peysakhovich, V. (2007). Human error in prolonged visual inspection tasks. *Human Factors*, 49(5): 802-811.
- Chavagnat, A. (1987). X-ray imaging for insect detection in seeds. *Seed Science and Technology*, 15(1): 123-134.
- Chowdhury, S. (2023). Historical perspectives on seed quality. *Agricultural History Review*, 71(1): 45-62.

- Dinkar, K., Singh, R. and Patel, V. (2024.) Challenges in AI adoption for precision agriculture. *Computers and Electronics in Agriculture*, 210: 107-118.
- ElMasry, G., Wang, N. and Vigneault, C. (2007). Hyperspectral imaging for seed quality. *Postharvest Biology and Technology*, 45(3): 334-345.
- ElMasry, G., Nakauchi, S. and Kamimura, H. (2019). Multispectral imaging in seed phenotyping. *Sensors*, 19(5): 1090.
- Gancarz, M., Wawrzyniak, M. and Gawrysiak-Wzgrzak, M. (2017). E-nose for fungal detection in grains. *Sensors*, 17(11): 2656.
- Kameswara Rao, N., Appa Rao, S. and Raju, C. D. (2017). Limitations of traditional seed testing methods. *Seed Science and Technology*, 45(2): 301-315.
- Ling-ling, Z. (2015). NIR prediction of hard seed percentages. *Spectroscopy and Spectral Analysis*, 35(9): 2567-2572.
- Masry, G. E., Nakauchi, S. and Islam, N. (2019). Integrated imaging for seed morphology and viability. *Trends in Food Science & Technology*, 88: 118-130.
- Medeiros, A. D., Nascimento, A. C. and Lima, J. F. (2020). Machine learning for seed quality classification. *Sensors*, 20(15): 4319.
- Musaev, A., Abdullaev, S. and Karimov, R. (2022). Soft X-ray for Brassicaceae germination prediction. *Journal of Plant Physiology*, 270: 45-52.
- Michelon, F., Schönauer, S. and Blasco, J. (2023). MSI classification of coated legume seeds. *Biosystems Engineering*, 228: 45-56.
- Mortensen, H. S., Toor, I. P. and Andersen, S. B. (2021). MSI for seed maturity in beets. *Plant Methods*, 17(1): 45.
- Nuttall, J., O'Leary, G. and Panozzo, J. (2024). Millimeter-wave radar for seed geometry. *Precision Agriculture*, 25(2): 567-582.
- Pandiselvam, R., Gopal, S. and Kumar, J. H. (2022). PLS-DA in NIR for seed discrimination. *Food Chemistry*, 385: 132-145.
- Priambodo, A., Nugroho, K. and Santoso, B. (2022). NIR moisture prediction in cacao. *Journal of Food Engineering*, 315: 110-120.
- Qiu, Z., He, D. and Zhang, X. (2018). FT-NIR soybean viability assessment. *Near Infrared Spectroscopy*, 26(3): 189-197.
- Raj, T. and Swaminarayan, P. J. (2015). Machine learning for remote seed grading. *International Journal of Agricultural Engineering*, 8(2): 145-152.
- Ren, J., Zhang, Y. and Li, X. (2020). Spectral-textural analysis for inbred lines. *Remote Sensing*, 12(12): 1998.
- Wang, Y., Li, Z. and Zhang, Q. (2023). MSI and omics for seed dormancy. *Frontiers in Plant Science*, 14: 1123456.
- Xia, Y., Bao, Y. and Wang, J. (2019). Hyperspectral imaging vs. NIR for seed viability. *Computers and Electronics in Agriculture*, 162: 745-753.

- Washington, D. C. and Roth, J. P. (1989). Expert systems for real-time seed analysis. *AI in Agriculture*, 3(1): 22-30.
- Xu, S., Wu, D. and Lin, H. (2021). E-nose for rice aging monitoring. *Food Chemistry*, 354: 129-140.
- Zhang, C., Liu, F. and Kong, W. (2020). Remote sensing for yield forecasting. *Remote Sensing of Environment*, 24: 111-123.



Insect in Forensic Science

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Abstract

Forensic entomology plays a crucial role in death investigations by using insect activity to reconstruct events surrounding decomposition. By analysing patterns of insect succession and temperature-dependent development, investigators can estimate the post-mortem interval (PMI) with considerable accuracy. Early colonizers such as blowflies provide immediate clues, while later-arriving species help track the progression of decay over time. Methods like ecological succession and thermo-biology allow experts to correlate insect life stages with environmental conditions, refining timelines even in complex cases. Advances in molecular identification have further improved species determination and enabled the recovery of genetic material from insect evidence. However, factors such as environmental variability, delayed insect access, and species misidentification can affect precision. Despite these challenges, insect-based analysis remains a valuable and evolving approach, contributing significantly to crime scene reconstruction, detection of toxins, and understanding of body movement after death in forensic investigations.

Introduction

Forensic entomology is a specialized branch of forensic science that focuses on the study of insects and other arthropods to aid in criminal investigations and legal proceedings (Amendt *et al.*, 2004). Insects may be found in cadavers (a dead human body, most commonly referring to a corpse used for medical education, scientific research, or forensic dissection) or elsewhere around crime scenes in the interest of forensic science. Forensic entomology is also used in cases of neglect and abuse of property, as well as subjects of a toxicology analysis to detect drugs and incidence of food contamination. Insect assemblages can help approxi-

mate a body's primary location, as some insects are unique to specific areas. In medico-criminal cases, the primary goal is often to determine the post-mortem interval to aid in death investigations. Forensic Entomology field is generally categorized into three main subfields: Urban Forensic Entomology, Stored-Product Forensic Entomology, Medico-Legal/Medico-Criminal Forensic Entomology. The field revolves around studying the type of insects commonly found in and on the place of interest, their lifecycles, their presence in different environments, and how insects assemblages change with the progression of decomposition. Insect succession patterns are identified based on the time a species

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spans in each developmental stage and the number of generations produced since the insect introduction to a food source. Forensic entomologists must take these variables into account when examining insect evidence. For example, higher temperatures speed up development, while cooler temperatures slow it down. By using established developmental data, entomologists can accurately determine the time of death, which is essential for establishing timelines in criminal investigations. Forensic entomology is primarily linked to death investigations but can also be used to detect drugs and poisons, pinpoint the location of an incident, and determine the timing and presence of wounds (Amendt *et al.*, 2004). By analyzing insect development alongside environmental data such as temperature, humidity and vapour density, forensic entomologists can estimate the time since death, as flying insects are attracted to a body shortly after death. This field also provides clues about antemortem, trauma and displacement of a body after death.

How does Forensic Entomology Work?

When someone dies, their body begins to get decomposed in a process called autolysis. Soft tissues break down releasing volatile molecules called apneumones. The release of apneumones like carbon dioxide, methane and ammonia acts like a dinner bell to insects, attracting them and altering their behaviour. This predictable process, where insects arrive and lay in eggs, allows forensic entomologist to glean all sorts of information from a corpse, including: The time between death and

finding a body (post mortem interval), where a crime took place & the cause of death.

Time of death for example, can be estimated by observing blowflies. These insects are remarkable for their keen sense of smell, allowing them to locate a body in as little as ten minutes. By identifying the species of fly and determining their life stage, forensic entomologists can estimate the time of death. This isn't an exact science, however. Factors like temperature, location and condition of the body can influence the development of these insects. This complexity is why forensic entomology is such a vital and specialized field.

Types of Forensic Insects

Necrophages: Organisms that feed on dead or decaying organic matter, typically attract to carcasses, play a vital role in decomposition by helping breakdown bodies. Ex- blowflies, flesh flies, certain beetles (Campobasso *et al.*, 2005).

Omnivores: Organisms that feed on both plant and animal matter, with a diverse diet that allows them to consume a wide range of food sources. Ex- beetles from the Dermestidae family.

Incidentals: Organisms that feed on a resource such as a decomposing body or other organic matter either by chance or as a secondary part of their diet. Ex- spiders, mites and certain beetles/ants.

Parasites and Predators (Parasitoids): Organisms that parasitize and actively kill their host by laying eggs on or inside it. The larvae then consume the host from the inside ultimately leading to its death. Ex- parasitic wasps and certain types of flies.

Key Insects used in Forensic Entomology (Catts and Goff, 1992)

- ✓ Blowflies
- ✓ Flesh Fly
- ✓ House Fly
- ✓ Cheese Skipper
- ✓ Sexton Beetle
- ✓ Clown Beetle
- ✓ Clerid Beetle



Image 1: Example of Dipteran insects used in Forensic Entomology

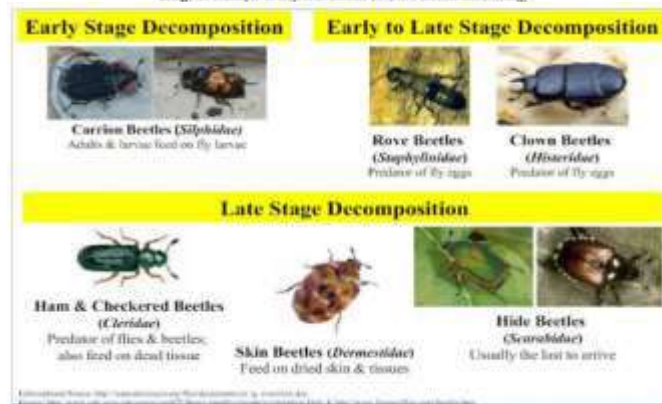


Image 2: Example of Coleoptera insects used in Forensic Entomology

Methods or Methodologies

Post-Mortem Interval (PMI) (Rani *et al.*, 2025):

The time since death, also known as the post-mortem interval (PMI), refers to the period between death and the discovery of the body. Estimating the PMI is crucial for understanding the movement of the body, as well as the manner and cause of death. It can also help establish connections between suspects and the death scene, detect toxins or drugs, and even identify the victim's DNA through insect larvae analysis. Accurate PMI estimation is especially important in death investigations where no witnesses are present. Insect evidence plays a key role in determining the PMI or estimating the period of insect activity, which is essential for narrowing down the crime timeline and aiding in the investigation and identification of suspects.

Estimation of Post-mortem interval (PMI)

Two common methods for estimating the Post-Mortem Interval (PMI), or the time since death, are *Ecological Succession* and *Thermo-biology*. Here's a brief explanation of each method:

Ecological Succession: Ecological succession refers to the predictable sequence of organisms, such as insects, bacteria, and fungi that colonize a body after death. This method is based on understanding how different species appear and thrive in the decaying environment at various stages of decomposition.

How it works?

After death, different insects and decomposers colonize the body in distinct stages. Blowflies (Calliphoridae) are the first to arrive, typically within the first 3 months. As the body begins to decay, flesh

flies (Sarcophagidae) follow. In 3-6 months, Dermestid beetles (Dermestidae) are attracted to the rancid fat and may remain for 1-3 years if the body dries out. Forensic entomologists examine the types of insects present, their developmental stages, and environmental factors like temperature and humidity to help estimate the PMI.

Stages of Decomposition: The decomposition of a human or animal body progresses through several distinct stages, each marked by unique changes in the physical and chemical structure of the remains. These stages create specific ecological environments for various insect groups, and their presence follows a predictable timeline:

Fresh Stage: Immediately following death, this stage is brief and characterized by autolysis, where cells and tissues begin to break down due to the lack of circulation and oxygen. Blow flies (Calliphoridae) and flesh flies (Sarcophagidae) are drawn to the body by its scent and moisture, laying eggs on or near the remains (Amendt *et al.*, 2004).

Bloat Stage (Days 2-7): In this phase, bacterial activity and the production of gases cause the body to bloat, which may result in distension or rupture. Blow flies, flesh flies, and certain beetles are attracted to the decaying remains during this stage (Pohjoismäki *et al.*, 2010).

Active Decay Stage (Days 5-13): As the body continues to break down, putrefaction intensifies, releasing fluids and strong odour. The body collapses, and tissues begin to liquefy. Blow flies, carrion beetles (Silphidae) and hister beetles

(Histeridae) are commonly present during this stage, further contributing to decomposition (Michaud and Moreau, 2020).

Advanced Decay Stage (Days 10-23): During this phase, most soft tissues are consumed, and the body becomes drier and more skeletonized. Insect activity decreases, but beetles, mites, and ants may continue to feed on the remaining tissue and other insects (Benecke, 2018).

Dry or Skeletal Stage (Days 18-90): In this final stage, which can last months to years depending on environmental conditions, the body is largely skeletonized with minimal soft tissue left. Carrion beetles and dermestid beetles (Dermestidae) are primarily associated with this stage, consuming the dry tissues and bones (Gennard, 2021).

Thermo-Biology

Thermo-biology is the study of how temperature influences the behaviour, development, and physiology of organisms, particularly blowflies (family: Calliphoridae). In forensic entomology, it plays a crucial role in estimating the Post Mortem Interval (PMI) by analysing the growth and development of blowfly larvae on a decaying body. The rate of larval development varies with temperature, affecting how quickly each developmental stage (egg, larva, pupa, adult) progresses.

Thermo-developmental Profile: Blowfly larvae undergo three stages (instars), which are characterized by the number of posterior spiracle slits. The first instar has U-shaped slits, the second instar has two slits, and the third instar has three slits. Forensic

entomologists use these features to assess larval development and estimate the time of death. Temperature directly impacts larval growth, and different blowfly species develop at distinct rates, allowing entomologists to refine PMI estimates.

Species Identification: Identifying the species is critical in PMI estimation, as different species of flies develop at different speeds, respond differently to temperature, and arrive at the body at varying times. While larvae from different species can appear similar morphologically, each species follows a unique developmental timeline. By accurately identifying the species, forensic entomologists can adjust for temperature influences, determine the decomposition stage, and reference known growth patterns to provide more precise PMI estimates.

Molecular Identification: DNA-based techniques enable precise species identification, especially when traditional methods face challenges due to specimen degradation or incomplete development. DNA analysis can also recover the victim's DNA from fly vomit or faeces, linking the insect to the victim and providing valuable forensic evidence. This molecular approach helps uncover genetic material that might otherwise be missed, offering additional clues for the investigation. Forensic entomology has extended to analyzing genetic material from a victim found in the gastrointestinal tracts of maggots (Stevens *et al.*, 2002).

Despite the advantages of advanced molecular techniques in forensic entomology, they are not without limitations. Their frequent unfeasibility

and limited availability, particularly in rural settings, present significant challenges. Additionally, closely related species may exhibit identical genetic sequences, or even show evidence of hybridization, complicating species identification. To address these issues, alternative methods like Restriction Fragment Length Polymorphism (RFLP) analysis have been proposed. This technique narrows the focus to a specific area of a nucleotide sequence, which can help reduce the risk of false inclusions and improve accuracy in forensic investigations (Rani *et al.*, 2025).

Challenges and Limitations

While forensic entomology is a powerful tool, it comes with challenges and limitations. Some factors that can affect the accuracy of PMI estimation and other forensic conclusions include (Mathew *et al.*, 2011).

- ✓ Environmental Variability
- ✓ Delayed Insect Access
- ✓ Species Miss-identification
- ✓ Limited Reference Data
- ✓ Influence of Drugs/Toxins
- ✓ Scavenger and Predator Interference
- ✓ Multiple Colonization Waves
- ✓ Indoor VS Outdoor Variability
- ✓ Geographical Differences
- ✓ Legal Scrutiny

Insects to be Examined

Flies and Beetles are two insects that are mainly used in an investigation of a crime. These two broad categories are further divided into more as

listed below (Sukontason *et al.*, 2004).

Flies

Blowflies: As mentioned previously, these flies are able to smell decaying flesh from over 16 km away and hence make for great indicators

Flesh Flies: Flesh flies feed on decomposing bodies, waste, manure, and other decaying materials. Only a few species, however, deposit their eggs in animals' open wounds. Because flesh flies are viviparous, they frequently give birth to decomposing human and animal bodies.

Cheese Flies: These flies are mostly associated with animal products and fungus. Their larvae are particularly prevalent in smoked fish, cured meat, cheese, and rotting animals. The existence of cheese fly larvae is critical for determining when people die.

Beetles: Dermestid Beetles, often known as skin beetles or hide beetles, infest a rotting body only after the soft tissues have been eaten by other creatures. They feed on skin and hair and are one of the most common insects found in human bodies by forensic entomologists.

Mites: Macrocheles mites feed on corpses early in the decomposition process, whereas Tyroglyphidae and Oribatidae mites feed on dry skin later in the process.

Moth: Moth larvae feed on the hair of mammalian carcasses and are among the last creatures to engage in the decomposition process.

Bone beetles: These are also obtained from decomposing bodies. Beetles in this family (Cleridae) feed on decomposing flesh, leaving pristine skeletal

remnants.

Carrion Beetles: While the larvae of carrion beetles feed on vertebrate corpses, the adults feed on maggots. These gentlemen are quite benefactors of social service since they have a proclivity for digging up and burying underground. little corpses

Hide Beetles: These insects feed on decomposing corpses and dried animal goods including bacon, dog treats, dried fish, and cheese. They often congregate around eating and mating resources.

Rove Beetles: Unlike carrion beetles, rove beetles feed on cadavers or corpses rather than decomposing flesh (carrion). They feed on maggots and other insect larvae found on dead animals.

Scarab Beetles are members of the Scarabaeidae family, which also includes dung beetles. They are often found on or around carrion and carcasses, mushrooms, the excrement, and rotting flesh and serve as the animal kingdom's cleaning crew.

Sap Beetles: These beetles are often found in close proximity to fermenting or decaying plant juices, such as rotting melons or tree sap. However, certain sap beetles infest corpses as well and are important in forensic entomology.

Clown Beetles: Also referred to as Hister bugs, these beetles are cunning. They often spend the day hiding under the body, emerging at night to feed on maggots or dermestid beetle larvae that thrive on it.

Dung Bugs: These beetles are very beneficial and feed on carrion. At any stage of decomposition, their larvae feed on decomposing fungus, dung and verte-

brate corpses.

Conclusion

Forensic entomology is an essential scientific tool in modern criminal investigations. By analysing insect succession and temperature-dependent development, experts can accurately estimate the post-mortem interval and reconstruct crime scenes. Advances in molecular identification have further strengthened its reliability. Overall, forensic entomology significantly enhances the accuracy and effectiveness of death investigations.

References

- Amendt, J., Krettek, R. and Zehner, R. (2004). Forensic entomology. *Naturwissenschaften*, 91: 51-65.
- A Summary of Concepts, Procedures and Techniques Used by Forensic Entomologists and Proxies - PMC
- Benecke, M. (2018). A brief history of forensic entomology. *Forensic Science International*, 285: 146-151.
- Byrd, J. H. and Castner, J. L. (2010). Forensic entomology-the utility of arthropods in legal investigation. 2nd ed. Boca Raton (FL): CRC Press.
- Campobasso, C. P., Linville, J. G., Wells, J. D. and Introna, F. (2005). Forensic genetic analysis of insect gut contents. *American Journal of Forensic Medical Pathology*, 26: 161-165.
- Catts, E. P. and Goff, M. L. (1992). Forensic entomology in criminal investigations. *Annual Reviews in Entomology*, 37: 253-272.
- Crawling clues: A comprehensive review on forensic entomology Ramesh M Maradi, Keerthana A and Somashekhar Gaddanakeri DOI: <https://doi.org/10.33545/26174693.2024.v8.i8Sm.1968>
- Forensic Entomology: How Insects Help Solve Crimes | Entomology and Nematology Online| University of Florida Entomology and Nematology Online Programs
- Gennard, D. E. (2021). Forensic Entomology: An Introduction. John Wiley & Sons; 2021.
- Mathew, D. G., Sathyan, P. and Vargheese, G. (2011). The use of insects in forensic investigations: An overview on the scope of forensic entomology. *Journal of Forensic Dent Science*, 3: 89-91.
- Matuszewski, S., Grzywacz, A. and Hall, M. (2020). Advances in entomological methods for decomposition timing. In: Current Concepts in Forensic Entomology. CRC Press; 2020. p. 17-34.
- Michaud, J. P. and Moreau, G. (2020). The insects colonizing a cadaver. *Current Opinion in Insect Science*, 39: 12-19.
- Wells, J. D., Wall, R. and Stevens, J. R. (2007). Phylogenetic analysis of forensically important *Lucilia* flies based on cytochrome oxidase I sequence: A cautionary tale for forensic species determination. *International Journal of Legal Med.*, 121: 229-233.
- William, L. and Krinsky. (2019). Forensic Entomology.

- Pohjoismäki, J. L., Karhunen, P. J., Goebeler, S., Saukko, P. and Sääksjärvi, I. E. (2010). Indoors forensic entomology: colonization of human remains in closed environments by specific species of sarcosaprophagous flies. *Forensic Science International*, 199(1-3): 38-42.
- Rani Bhuyan, P., Borah, B. K., Rajkumari, P., Bora, B., Borah, N. and Chaya, S. (2025). Forensic entomology: Unraveling the secrets of insect evidence. *International Journal of Advances in Biochemistry Research*, 9(2S): 582-588.
- Stevens, J. R., Wall, R. and Wells, J. D. (2002). Paraphyly in Hawaiian hybrid blowfly populations and the evolutionary history of anthropophilic, 11: 141-148.
- Sukontason, K. L., Sukontason, K., Piangjai, S., Boonchu, N., Kurahashi, H., Hope, M., *et al.* (2004). Identification of forensically important fly eggs using a potassium permanganate staining, 35(5): 391-395

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Classical PSR traits include

- and reactive oxygen species (ROS).

A key transcriptional Arabidopsis Pi signaling module comprising the MYB transcriptional factor PHR1, associated microRNA miR399, and ubiquitin-conjugating enzyme PHO2, are also involved in controlling Pi uptake and translocation, via regulating PHT1 transporters and other genes related to Pi. These Pi-specific parts interconnect with more global carbon (C) and sugar communication systems, suggesting intensive C P nutritional crosstalk.

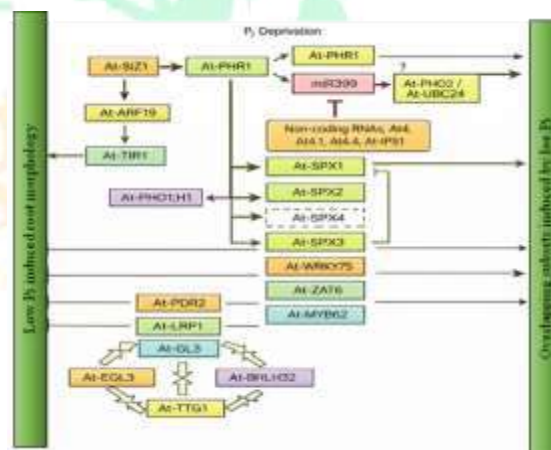


Fig. 1: A model for the plant Pi regulon

For simplicity, the interactions of genes that are induced (heavily outlined boxes), do not respond (lightly outlined boxes) or are repressed (dashed boxes) by Pi deficiency in arabidopsis are shown. At-SIZ1 (SAP and Miz1 domain-containing SUMO E3 ligase 1); At-PHR1 (PHosphate Starvation Response 1); At-PHF1 (PHosphate transporter traffic Facilitator 1); miR399 (MicroRNA 399); At-PHO2/At-

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UBC24 (PHOSPHATE 2/Ubiquitin-Conjugating Enzyme 24); At4, At4.1, At4.4 (phosphate starvation-induced non-coding RNAs); At-IPS1 (Induced By Phosphate Starvation 1); At-SPX1, At-SPX2, At-SPX3, At-SPX4 (SYG1/Pho81/XPR1 domain-containing proteins 1-4); At-PHO1/At-PHO1;H1 (Phosphate 1); At-WRKY75 (WRKY transcription factor 75); At-ZAT6 (Zinc finger of Arabidopsis thaliana 6); At-MYB62 (MYB domain transcription factor 62); At-ARF19 (Auxin Response Factor 19); At-TIR1 (Transport Inhibitor Response 1); At-PDR (Phosphate Deficiency Response 2); At-LRP1 (Lateral Root Primordium 1); At-GL3 (GLABRA 3); At-EGL3 (Enhancer of Glabra 3); At-TTG1 (Transparent Testa Glabra 1); At-bHLH32 (basic Helix-Loop-Helix transcription factor 32).

Sugar as a systemic modulator of PSR

Sugar is required for PSR: Previous genetic and physiological research on Arabidopsis showed that exogenous sugars are required to induce PSR traits to their maximum in the case of Pi deficiency. Karthikeyan *et al.* (2007) demonstrated that normal responses to Pi starvation, such as the typical root architectural changes and phosphate starvation-induced (PSI) genes, cannot occur without sugar; absent sugar, these responses are inhibited with low extracellular Pi. Correspondingly, experiments that regulated carbohydrate concentrations in the media of growth showed that more supply of sucrose to roots in low-Pi conditions promotes the expression of Pi-sensitive genes and amplifies morphological PSR phenotypes. Genetic and genomic analysis has

proven that sucrose is a universal controller of Pi-starvation responses. Transcriptomics were employed by Lei *et al.* (2011) to reveal that the availability of sucrose globally modulates PSR genes expression, and it indicates that sucrose is not just a simple source of energy but a signal that coordinates PSR on a whole-plant basis.

Sucrose induces shoot-root communication:

When Pi is deficient, photosynthetic leaves allocate carbon and export more sucrose to the roots, which provides systemic information on the status of the shoot PI and energy. Pi-starvation effect on root developmental reactions can also be recreated by adding sucrose to the root media, which points to a model whereby Pi starvation signal mobilized by shoots is transported to the root system to stimulate and enhance PSR. Recent research reveals that the local Pi concentration interacts with the supply of sucrose to fine-tune the root responses, which implies that plants combine both local and systemic signals to optimize the uptake of Pi.

Pathways of sugar signaling in PSR

Hexokinase dependent sugar sensing: One of the most important glucose sensors, HXK1, is a widely acting sugar signaling protein incorporating sugar status into developmental and stress responses. Transcriptomic analyses have also evidence of disturbed HXK1 and other signaling elements expression under Pi starvation, and hexokinase-dependent sugar perceptions have been proposed to tune networks of PSR genes. The sugar sensor gene HXK1 increases in response to low levels of sucrose

in the manipulation of Pi deficiency, showing that sugar sensing alters the balance between growth and photosynthesis and stress response in conditions where Pi is a limiting factor.

SnRK1 and Tre6P network: The SnRK1 (SNF1-related kinase 1) and trehalose-6-phosphate (Tre6P) signaling hub is a close indicator of sucrose availability and balances energy status and carbon allocation. Though sugar starvation experiments have provided the majority of mechanistic information, SnRK1-Tre6P signaling has been linked to the orchestration of responses to compounding sugar and nutrient stresses, such as Pi deficiency. In rice, sugar-related mutant alterations in cell-wall biosynthesis-associated gene (e.g., OsCSLF6) regulate the levels of sucrose and the expression of Pi signaling genes including OsIPS1 and OsPHO2, which further implicates a relationship between carbon metabolic regulation and Pi signaling.

Post-transcriptional and translational regulation:

The sugar signaling also occurs at post-transcriptional levels such as the regulation of the mRNA stability, the translation and the protein turnover. Not only is transcriptional regulation of the biosynthetic genes, but post-transcriptional mechanisms to finely tune enzyme abundance and activity are involved in the modulation of anthocyanin biosynthesis, ROS metabolism and lipid remodeling under Pi starvation.

Crosstalk between sucrose and canonical Pi signaling (PHR1-miR399-PHO2): PHR1 regulates

the production of miR399 by releasing the miR399 native PHR1 in response to Pi deprivation, miR399 represses PHO2, and PHO2 can regulate the expression of Pi transporters and other proteins associated with Pi. The presence of sugar changes the expression of most of the PHR1 target genes and Pi transporters indicating that sucrose signaling integrates into or regulates this central Pi signaling pathway. An example is that the induction of PHT1 family transporters as well as PHF1 is influenced by the levels of sucrose. They are able to control the expression of negative regulators like NLA1 (Nitrogen Limitation Adaptation 1) and hence the ability to increase or decrease Pi uptake capacity in accordance with combined C and P status. On a systems level, it is indicated that overlapping sets of many genes that respond to Pi and to sucrose are formed, meaning that transcription factors across sugar signaling pathways interact with PHR1-regulated networks. This combination makes sure that the process of Pi acquisition and remobilization is synchronized with the supply of carbon to the plant, so that discrepancies between energy requirements and the supply of nutrients will not be produced.

Physiological effects of sucrose on PSR outputs

System architecture and development: Pi deficiency has a powerful modulatory effect on root system responses to sugar supply. Pi starvation generally suppresses primary root growth and stimulates the growth of lateral roots and the growth of root hair in Arabidopsis, although these responses

are significantly decreased when the sugar supply is constraining. Pi-deficiency-induced root remodeling is improved by Pi-deficiency-induced root remodeling by supplemental sucrose, which suggests that Pi-deficiency-induced root remodeling is positively regulated by sucrose.

Photosynthesis and energy allocation: Pi starvation has effects on photosynthesis by changing the availability of ATP and Pi to the Calvin cycle and photophosphorylation. Recent transcriptomic studies indicate that in the adequate supply of sucrose, photosynthesis-related genes and chlorophyll metabolism are suppressed during Pi deficiency, and additional ATP is directed towards stress responses but not development. Conversely, photosynthesis genes may be more or less upregulated under the conditions of the scarcity of carbohydrates (sucrose limitation). This implies that the availability of sucrose assists in regulating the distribution of ATP and reducing power among plants between growth, defense and Pi acquisition under stress.

Accumulation of anthocyanin, ROS and lipid remodeling: Pi starvation usually leads to accumulation of anthocyanin and alteration of ROS production, which are significant in stress acclimation and antioxidant defense. Pi deficiency induces the synthesis of anthocyanin using sucrose; in the situation of a low concentration of sucrose, the anthocyanin biosynthesis pathways and the ROS-related genes are less activated resulting in a decreased level of anthocyanin and ROS. Membrane lipid metabolism during Pi starvation is also regula-

ted by Sucrose availability in the contribution to Pi cycling through the phospholipid-galactolipid pathway.

Signalling of carbon and phosphorus

The cross regulation of carbon metabolism and Pi signaling is one of the key axes of plant nutrient homeostasis. Rice and Arabidopsis mutations in carbon metabolism (e.g., OsCSLF6) have been found to modify the amount of sucrose and consequently the expression of Pi-starvation regulating genes (e.g., IPS1, INDUCED by phospho-hostile starvation 1) and PHO2, demonstrating that carbon metabolic status contributes to Pi regulatory circuits. On the other hand, the starvation of Pi may provide feedback on the carbon metabolism affecting the levels of starch and sucrose, respiration, and the growth dynamics. Sugar signaling can therefore be considered as an integrator, such that plants can detect carbon and Pi availability and respond by adjusting development, metabolism and gene expression. This interaction is essential in natural soils where there are simultaneous changes in light, carbon provision, and Pi availability and there are significant implications of this interaction in enhancing crop use of Pi through low-fertilizer agriculture.

Conclusions and future directions

All in all, it is possible to say that sucrose is a metabolic resource and a signaling molecule that controls phosphate starvation reactions on morphological, physiological, and molecular levels. Among the open questions, one can recognize defining the

specific molecular connections between sucrose sensors (HXK1, SnRK1-Tre6P) and canonical Pi regulators (PHR1-miR399-PHO2) as well as how sugar-dependent post-transcriptional regulation has been involved in shaping PSR in various tissues and developmental stages. This will be critical in future work involving the integration of genetics, multi-omics, and modeling in various crops to take advantage of sugar -Pi signaling crosstalk to breed plants with an improved efficiency of Pi acquisition and utilization under sustainable fertilization regimes.

References

- Bari, R., Datt Pant, B., Stitt, M. and Scheible, W. R. (2006). PHO2, microRNA399, and PHR1 define a phosphate-signaling pathway in plants. *Plant Physiology*, 141(3): 988-999.
- Chen, X., Wang, M., Tian, Q., Liu, L., Wang, H., Song, X., ... and Han, X. (2025). The role of sucrose in phosphate starvation response: transcriptomic and physiological insights in *Arabidopsis thaliana*. *BMC Plant Biology*, 25(1): 1606.
- Hammond, J. P. and White, P. J. (2011). Sugar signaling in root responses to low phosphorus availability. *Plant Physiology*, 156(3): 1033.
- Jin, C., Fang, C., Yuan, H., Wang, S., Wu, Y., Liu, X., ... and Luo, J. (2015). Interaction between carbon metabolism and phosphate accumulation is revealed by a mutation of a cellulose synthase-like protein, CSLF6. *Journal of Experimental Botany*, 66(9): 2557-2567.
- Karthikeyan, A. S., Varadarajan, D. K., Jain, A., Held, M. A., Carpita, N. C. and Raghothama, K. G. (2007). Phosphate starvation responses are mediated by sugar signaling in *Arabidopsis*. *Planta*, 225(4): 907-918.
- Lei, M., Liu, Y., Zhang, B., Zhao, Y., Wang, X., Zhou, Y., ... and Liu, D. (2011). Genetic and genomic evidence that sucrose is a global regulator of plant responses to phosphate starvation in *Arabidopsis*. *Plant Physiology*, 156(3): 1116-1130.
- Rouached, H., Arpat, A. B. and Poirier, Y. (2010). Regulation of phosphate starvation responses in plants: signaling players and cross-talks. *Molecular Plant*, 3(2): 288-299.
- Wang, K., Li, M., Zhang, B., Chang, Y., An, S. and Zhao, W. (2023). Sugar starvation activates the OsSnRK1a-OsHHLH111/OsSG11-OsTP P7 module to mediate growth inhibition of rice. *Plant Biotechnology Journal*, 21(10): 2033-2046.
- Wang, M., Zang, L., Jiao, F., Perez-Garcia, M. D., Ogé, L., Hamama, L., ... and Chen, J. (2020). Sugar signaling and post-transcriptional regulation in plants: an overlooked or an emerging topic? *Frontiers in Plant Science*, 11: 578096.
- Xiao Juan Yang and Finnegan, P. M. (2010). Regulation of phosphate starvation responses in higher plants. *Annals of Botany*, 105(4): 513-526.

Insects in Crime Solving: Nature's Detectives

S. Poornima

Introduction

Fingerprints, DNA, and astute detectives are frequently associated with criminal solving. But one of the most surprising yet effective instruments for research comes from the natural world: insects. Insects are used by the scientific discipline of forensic entomology to find important hints regarding crimes. Insects serve as silent witnesses, assisting investigators in solving mysteries that might otherwise go unsolved, such as establishing whether a body has been moved or estimating the time of death.

How Insects reveal the time of death?

Insects are crucial for determining the post-mortem interval (PMI), or the amount of time since death. Some insects are the first to reach a decaying body, particularly blowflies. They lay eggs, which grow into pupae, adult flies and larvae (maggots). Forensic specialists can ascertain the duration of the body's exposure by examining the life stages of these insects. Insects have a natural "clock" that aids investigators in determining the exact moment of death since their development follows a predictable pattern that is impacted by temperature.

Insect Succession: A Decomposition Timeline

Different species of insects are attracted to a body at different stages of decomposition. This process is called insect succession.

Early stage: flies and maggots

Middle stage: beetles and other scavengers

Late stage: mites and insects feeding on dry remains



Beyond Time: Clues about the Crime Scene

Insects can provide more than just timing they can offer clues about the location and circumstances of death. For example:

- ✓ Certain insects are found only in specific environments (urban, forest, aquatic)
- ✓ Presence of unusual species may suggest the body was moved
- ✓ Toxins or drugs in the body can sometimes be detected in feeding larvae

These tiny creatures can therefore help reconstruct events leading up to a crime, making them invaluable to forensic investigations.

Insects as Indicators of Environment

Insects can act as important clues about the environment where a crime occurred. Different species are adapted to specific habitats such as forests, urban areas, or water bodies. By identifying the insects found on a body, investigators can determine the type of environment and whether the

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body has been moved. For example, the presence of aquatic insects may suggest the body was in water, while certain beetles indicate dry land conditions. Thus, insects help reconstruct the location and surroundings of a crime scene.

Detecting Drugs and Poisons through Insects

In forensic investigations, insects can help detect the presence of drugs and poisons in a body. When insects such as maggots feed on decomposing tissues, they absorb any chemicals present, including toxins or narcotics. Even if the body is too decomposed for direct testing, these substances can still be identified by analyzing the insects. This process, known as entomotoxicology, allows scientists to detect drugs like alcohol, pesticides, or other poisons. Such evidence can provide valuable clues about the cause of death and support criminal investigations.

Limitations and Challenges in Forensic Entomology

- ✓ Weather conditions can affect insect activity
- ✓ Incorrect identification may lead to errors
- ✓ Requires expert knowledge and careful analysis

Conclusion

Insects may seem insignificant in everyday life, but in the world of crime solving, they are powerful allies. Through the science of forensic entomology, these small organisms provide critical evidence that helps uncover the truth. Acting as nature's detectives, insects remind us that even the tiniest forms of life can play a major role in delivering justice.

References

- Anderson, G. S. (2011). *Entomology and Death: A Procedural Guide*. Entomology and death: A procedural guide. Forensic Entomology Partners.
- Byrd, J. H. and Castner, J. L. (Eds.). (2010). *Forensic Entomology: The Utility of Arthropods in Legal Investigations*. *Forensic entomology: The utility of arthropods in legal investigations* (2nd ed.). CRC Press.
- Goff, M. L. (2000). *A Fly for the Prosecution*. A fly for the prosecution: How insect evidence helps solve crimes. Harvard University Press.

A Canopy of Care for those Who Feed the World

Repalle Shanmukh Rao, Pratik Kharade and Siddhi Indulkar

Introduction

India, an agrarian economy, employs over 44.1% of the total workforce as per periodic labour force survey 2023-24 (Govt. of India, Ministry of Finance, January 2025). Despite technological advancements, small and marginal Indian farmers continue to rely heavily on manual labour for plant care activities. These activities often expose workers to extreme weather conditions, particularly in India's sweltering summers and heavy rain. In response to these hardships, an innovator from Telangana, being supported by the National Innovation Foundation-India, has designed a practical solution: a mobile shed. This lightweight and easy-to-assemble structure provides much-needed shade and protection, enabling farm workers to perform their duties more comfortably and efficiently, even in extreme weather conditions. By introducing this innovative mobile shed to a wider audience, the creator aims to improve working conditions for agricultural labourers across India.

Genesis: Indian agriculture working culture is deeply rooted in tradition, family and community. Going hand in hand with cutting-edge technologies,



Innovator- Mr. Repalle Shanmukh Rao

peasant or small scale farmers rely on manual field practices which sometimes goes up to 10-12 working hours under the blazing sun (Economic Challenges faced by Agricultural Labourers in India, 2023). With the Indian Meteorological Department reporting a 0.7°C increase in average temperatures between 1901 and 2018, the challenges faced by farm workers have intensified (Sharma, 2020). An increase of about 0.5 °C is anticipated across India by 2030, with temperatures projected to rise by 2-4 °C by the century's end (Joint Global Change Research Institute and Battelle Memorial Institute, 2009).

Farm workers working in such a condition faces significant health risks including heat exhaustion, heatstroke, dehydration and other skin disorders. According to one projection, by 2030 the agricultural sector is expected to contribute to 60 % of the total global loss in working hours caused by heat stress, (International labour Organization, Geneva, 2019). People engaged in farming are classified as a high-risk occupational group, with greater susceptibility to harmful health effects driven by rising worldwide temperatures. The likelihood of fatal incidents from heat stress is 35 times higher among farm workers than among those working in industrial occupations (Moussa El Khayat *et al.* 2023

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). By taking this concern in mind an Innovator Repalle Shanmukh Rao from Telangana designed and constructed the mobile shed-canopy of care, using easily available material.

Innovation: Mobile Shed is portable, light weight and easily assemble solution for the above concern. This canopy is designed to withstand moderate rain and wind along with sun providing protective environment. The structure is made up of mild steel pipes and covering cloth. For easy transportability it is provided with wheels. General structure can accommodate 5-6 working labour at one place but structure can be scaled up or down as per requirements. Structure can also be provided with side wall for more protection. Shed can be moved manually as worker move forward.

Detailed Construction: The base frame (1) is constructed using a 1.25 x 1 inch, 3-feet long rectangular pipe, to which two 12-inch diameter wheels (7) are attached for mobility. A vertical column (8), made from a 1.25 x 1 inch, 7-foot long pipe, is welded at the centre of the base frame (1). The extruded section of the middle upper beam (3) (20 x 20 mm and 20 feet in length), is inserted into the column (8), providing support on both sides. Side trusses (5), each measuring 20 x 20 mm and 3 feet long, are secured to the middle upper beam (3) using nuts and bolts. These trusses are further supported by diagonal struts (4) of 20 x 20 mm and 3 feet in length, attached to both sides for add stability. The side upper beams (2) are then connected to the side (5) and middle (6) trusses, again using nuts and bolts, on

both sides of the upper middle beam (3). Additional middle trusses (6) are incorporated to increase the structure's strength. Finally, the entire frame is covered with a tarpaulin sheet (9) that blocks sunlight, providing effective shade.

Benefits

- ✓ Shed reduces the health risk due to exhaustion, dehydration and rainy weathered induced illness.
- ✓ Minimize disruption in the work due to harsh weather condition result in timely field operation.
- ✓ Enhanced working condition, productivity and strengthen relationship between farmer and labours.

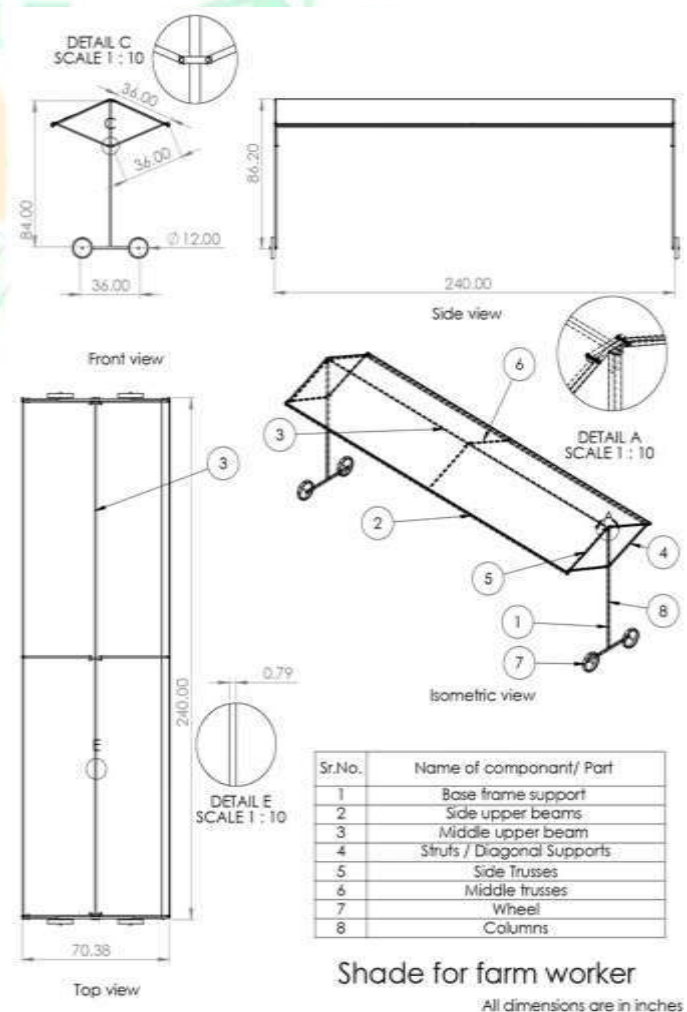


Fig.1: Schematic diagram for mobile shade



Fig. 2: Farmers working with mobile shed

Conclusion

Mobile shed is correct example that Grassroot innovators are the perfect diagnostician of the field problems and trouble-shooter for the same. They empathize the problem as their own and solve the same. Mobile Shed designed by Shanmukh Rao can effectively address the farm worker challenges and will provide them relief from extreme weather condition. It also enhances workers well-being, productivity, safety and contribute towards the sustainable agriculture practices. Recognizing the impact and benefits of the innovation, Shanmukh Rao, an innovator is eager to publicize the mobile shed to wider audience. Authors hope for encouraged adoption and also further advancement. Publicizing it would help in extend its reach among the farm workers and improve the condition and productivity of India's Agricultural work force.

References

- Economic Challenges Faced by Agricultural Labourers in India. (2023, December 12). Retrieved from <https://agriculture.institute/indian-agricultural-development/economic-challenges-agricultural-labourers-india/>
- Government of India, Ministry of Finance. (January 2025). Indian Economic Survey 2024-25 Chapter 12: Employment and Skill Development: Existential Priorities. Department of Economic Affairs, page no. 369, section 12.14. Retrieved from <https://www.india-budget.gov.in/economicsurvey/doc/eschapter/echap12.pdf>
- International labour Organization, Geneva. (2019). “Working on a Warmer Planet: The Impact of Heat Stress on Labour Productivity and Decent Work”). Retrieved from https://www.ilo.org/sites/default/files/wcmsp5/groups/public/@dgreports/@dcomm/@publ/document/publication/wcms_711919.pdf
- Joint Global Change research Institute and Battelle Memorial Institute, Pacific Northwest Division. (April 2009). “India: The Impact of Climate Change to 2030 - A commissioned Research Report”. National Intelligence Council. Retrieved from https://www.dni.gov/files/documents/climate2030_india.pdf
- Moussa El Khayat, Dana A. Halwani, ... and Rima R. Habib. (2022). Impacts of Climate Change and Heat Stress on Farm-workers' Health: A Scoping Review. *Frontiers in Public Health*, doi:10.3389/ fpubh.2022.782811

Edible Coatings: A Safe Approach for Preserving Freshness of Fruits and Vegetables

Sarvesh Kumar Sen, Nirmala Singh and Kalyan Barman

Introduction

Fruits and vegetables are essential constituents of daily human diet. They are reservoir of vitamins, essential minerals, dietary fibres, antioxidants, and several health promoting bioactive compounds. Consumption of fruits and vegetables has been associated with reduced risk of several diseases. However, fruits and vegetables are highly perishable and during postharvest handling, a considerable portion of the total harvest is lost due to losses due to spoilage and ongoing metabolic activities. The shelf life of fruits and vegetables can be extended by application of edible coatings over the produce surface. These coating materials do not have any adverse effects on health, thus can be consumed safely as a part of the product. In addition to being environmentally benign, edible coatings or films extend the shelf life of fruits and vegetables. To preserve fresh fruits and vegetables, novel edible films and coatings containing a variety of edible herbs and antibacterial chemicals have been created recently. Edible coatings to keep moisture and stiffness intact. They regulate respiration rate, development and maturation. In fruits and vegetables like tomatoes, cucumbers, cherries, etc., edible coatings stop oxidative browning and reduce the growth of microorganisms.

Postharvest losses of fruits and vegetables mainly occur due to microbial spoilage, moisture loss, respiration and physiological disorders. The important quality factors of fresh product contributing to the marketability are colour, appearance, texture, flavour, nutritional value and microbial safety. Edible coating has emerged as an eco-friendly approach to preserve the quality attributes and extend shelf life of fruits and vegetables. Considering the different physiological characteristics of fruit and vegetables, the development of edible coating materials for preservation of fruits and vegetables has attracted a lot of interest among the researchers. Among edible coatings, beeswax, chitosan, carnauba wax, shellac are widely used owing to their excellent barrier properties, natural origin and regulatory acceptance for use in different food products.

Edible coatings: Edible coatings have been used for centuries to preserve different food products. The first use of edible coatings was reported from China in 12th century. Fruit waxing was not developed until 1922, when it was first used commercially on fruits and vegetables. Edible coating is defined as a thin layer of edible material applied to the surface of fruits or vegetables as a semi-permeable barrier to gases and water vapour. These are effective in reducing respiration rate, transpiration rate, oxidati-

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on, moisture loss, solute migration, microbial spoilage and reducing physiological disorders. Hence, edible coatings can enhance shelf life and marketability of produce without compromising its quality. Based on the origin, edible coatings can be broadly categorized into two types, plant based and animal based.

Plant based edible coatings

Starch: Starch is widely used as a biopolymer because of its acceptability, biodegradability and thermoplastic properties. Starch consists of two kinds of polysaccharides, amylose and amylopectin. The amylose is responsible for the production of films and firmness of gels. Starch-based coating solutions usually have low water resistance and water vapour barrier as the result of hydrophilic components. Therefore, a plasticizer is required for creating a flexible starch-based coating and also increasing the mechanical properties. Starch can be obtained from different sources such as maize, potato, cassava, rice, and wheat. Depending upon the sources and produce types, optimal concentrations of starch typically range from 3.0-5.0%.

Carboxymethyl cellulose: Carboxymethyl cellulose (CMC) is a water-soluble cellulose derivative obtained from plant cell walls, and is valued for its excellent film-forming ability due to its biocompatibility with other water-soluble materials, transparency, and non-toxic nature. CMC effectively lowers oxygen diffusion, while allowing adequate carbon dioxide exchange, helping to prevent anaerobic respiration. Major advantage of CMC is its

stability over a wide range of temperatures and humidity. Effective CMC concentration ranges from 1.0-5.0% (w/v) for application as coating material.

Pectin: Pectin is a hetero-polysaccharide with a branching structure, white in colour, amorphous and colloidal carbohydrate of high molecular weight occurring in fruits. It is widely used in fruit jellies, pharmaceuticals and cosmetics for thickening and emulsifying properties and ability to solidify to a gel. Pectin is present in the primary cell walls and middle lamellae of plants and fruits, and associated with cellulose, hemicellulose and lignin structures. Pectin based coatings cause aroma preservation and serve as an excellent barrier to oxygen and carbon dioxide. They can be used in fresh and minimally processed fruits and vegetables, such as avocado, apple, apricot, chestnuts, berries, guava, melon, papaya and walnuts. Optimal concentration of pectin ranges between 1.0-2.0% (w/v), often combined with a plasticizer such as glycols (0.5-1.0%).

Alginate: Alginate is a natural polysaccharide extracted from brown sea algae, namely *Laminaria hyperborean*, *Macrocysti pyrifera* and *Ascophyllum nodosum* that is composed of two uronic acids: β -D-mannuronic and α -L-guluronic acid residue linked by 1-4 glycosidic bonds. Alginate-based edible coatings and films attract interest for improving quality and extending the shelf-life of fruit, vegetable, meat, poultry, seafood and cheese by reducing dehydration. Alginate at the concentration of 1.0-2.0% has been found most effective for application in horticultural commodities.

Carnauba wax: Carnauba wax is a natural, edible wax obtained from the leaves of the carnauba palm (*Copernicia prunifera*), a native palm of north-eastern Brazil. It forms a thin, glossy and semi-permeable layer on the surface of fruits. It is a GRAS (Generally Recognised as Safe) compound, highly hydrophobic in nature and provides excellent moisture barrier property. Chemically, carnauba wax is composed mainly of long-chain fatty acid esters, alcohols, hydrocarbons and resins which contribute to its hardness and high melting point. This high melting point makes it stable under warm storage and transport conditions, an advantage under climate change induced temperature fluctuations. For most horticultural produce, 0.5-1.0% carnauba wax coatings were reported effective in preserving postharvest quality.

Carrageenan: Carrageenan is water soluble polymer, consisting of linear chain of partially sulphated galactans, which have ability to form coating or film forming. Carrageenan is a sulphated polysaccharide, extracted from red algae *Eucheuma cottonii*, belongs to the Rhodophyceae family. Carrageenan coatings form a gelation mechanism during moderate drying process, leading to formation of a three dimensional network by polysaccharide double helical and to a solid coating or film after solvent evaporation. Use of carrageenan has been reported both home scale as well as in large industries. Carrageenan coating forms a selective permeable membrane for oxygen and carbon dioxide thereby modifying the internal atmosphere of fruit

and extending its shelf life. Carrageenan coating at 1.0-1.5% concentration is most effective in different horticultural produce.

Agar: Agar gum is a galactose polymer, obtained from red seaweed of Rhodophyceae family. Agar is hydrophilic, colloidal in nature that contains a mixture of agro pectin and agarose. Generally, it is used as microbiological media to give firmness. Agar forms a strong gel melting point for above the initial gelation temperature. Agar gels dissolve at high temperature and set at low temperatures, due to its ability to absorb it and form a stiff gel at low concentrations. The food sector makes extensive use of agar. Agar at 0.2% reduces disease incidence and fungal rots in banana. Agar coating in the range of 0.5-3.0% can be used for different horticultural produce.

Animal based edible coatings

Beeswax: Beeswax is a natural wax secreted by the honeybees (*Apis spp.*). It is hydrophobic in nature and generally composed of long-chain fatty acids, esters and hydrocarbons. Beeswax helps to maintain quality of fruits by forming a protective layer that reduces moisture loss, lowers respiration rate and ethylene diffusion. Application of beeswax imparts surface gloss thereby improves appearance and also act as a barrier against microbial invasion. Beeswax is commonly used on fruits like apple, citrus, mango, pear and plum. It is often applied as an emulsion, sometimes combined with natural antimicrobials or essential oils. It improves shine and consumer appeal, effective in reducing weight loss and shrivel-

ling. However, care should be taken during application, as application of thick coating may restrict gas exchange, leading to anaerobic respiration. Beeswax is widely approved as an edible coating for food use in most major countries including United States, (U.S. Food and Drug Administration), European Union (EU regulation), India (Food Safety and Standards Authority of India; FSSAI). Beeswax at 2.0% concentration significantly reduces weight loss and maintains firmness, at 1.0% concentration in guava significantly improves weight, vitaminC, acidity.

Shellac: Shellac is a natural resin obtained from the secretion of the lac insect (*Kerria lacca*), that has been widely studied as an edible film material. The insect is mostly cultivated on the host trees in India and Thailand. Moreover, being an animal-based resin, it has natural properties and good biocompatibility and biodegradability. Shellac is composed of hard resin and soft esters, containing hydroxyl and carboxyl groups. It is an excellent film forming agent with good barrier properties that is soluble in both alcohol and alkaline solutions. The shellac has been primarily used in food and agro-based industries for water, gas, lipids and microbial spoilage protection and eventually prolonging the shelf life of the food products. It is extensively used for coating of apple, citrus fruits, pomegranate and tropical fruits in commercial pack houses. However, it has limitations of poor mechanical strength and brittleness. The application of shellac as an edible coating material is approved in countries like United

States (United States Food and Drug Administration), European Union (EU Regulation), also in Australia, New Zealand and Canada by Joint FAO/WHO Expert Committee on Food Additives (JECFA) and also in India (FSSAI). The optimum concentration of shellac is about 1.0-1.25% for commercial fruit coating.

Chitosan: Chitosan is a natural, biodegradable edible coating material derived from chitin, obtained mainly from the shells of crustaceans such as shrimps and crabs. It is widely used due to its excellent film-forming, antimicrobial and antifungal properties. Chitosan is particularly effective in controlling postharvest diseases caused by fungi such as *Botrytis*, *Colletotrichum* and *Penicillium*, making it highly valuable for fruits like strawberry, grape, apple, mango and banana. Chitosan is accepted as a food additive or coating in parts of Asia, has a GRAS (Generally Recognized As Safe) recognition in the United States for specific uses, and require case by case approval in the EU and other region depending on formulation and application. In strawberry, chitosan at 0.5-1.0% concentration reduces fungal decay, 1.0% concentration reduces weight loss in grapes and reduces climacteric peak in mango.

Gelatin: Gelatin is a protein-based edible coating derived from collagen present in animal skin, bones and connective tissues. Gelatin is a form of collagen hydrolysed and exhibits unique gelling, colloidal properties and a good ability to form coatings. Gelatin has long been widely and extensively used as a gelling and foaming agent in desserts, baking,

jellied meats, candy, ice cream, etc. Gelatin is approved as an edible coating in major countries including the USA, EU, India, Canada, Australia, Japan and China under food safety. However, its animal origin may restrict its use in vegetarian, vegan, halal or kosher markets. Gelatin at 1.0-2.0% concentration is optimal as an edible coating in horticultural crops.

Casein: Casein is a protein-based biopolymer obtained from milk, found in the form of micelles, present in all casein species. One micelle has molecular weight of roughly 105kDa and contains 104 peptides. Casein being an amphipathic, has hydrophilic and hydrophobic ends, that is frequently employed in emulsion preparation. The most prevent casein product is caseinate, which dissolves readily in water. Casein-based films are realized by means of casting or extrusion, while coatings are synthesized by mechanisms similar to solution casting and are applied generally to fruits and vegetables either by dipping or spraying method. Casein forms edible coating generally within 1.5-3.0% (w/v) range, which is most effective in preserving the fresh produce quality.

Zein: Zein is a protein, synthesised from corn gluten flour, obtained from maize. One of the by-products of corn starch synthesis by corn gluten is zein protein, which is considered as a component of corn prolamin. Zein dissolves in alcohol and glycol esters but is immiscible in water. Zein has high binding and film making properties, thus provide a good oxygen barrier and is useful in preventing colour change,

softening, weight loss as well extending the shelf life. Corn zein has about 800-fold superior water vapour barrier property. Surface coating of fruits with zein at 1.0-2.0% concentration found effective for delicate fruits like berries while, 2.0-3.0% coating is effective for fruits like apple, mango and citrus.

Methods of application

Edible coatings can be applied to fruits and vegetables by different methods as mentioned below

Dipping: In this method, fruits and vegetables are immersed in a coating solution for a brief period of 30 seconds to 2 minutes, ensuring a uniform layer over the entire produce surface.

Brushing: This method is used in commercial fruit waxing lines, where rotating brushes spread the coating material evenly over the fruit surface. It is effective for applying shellac or carnauba wax on apples, citrus and pears, enhancing gloss and reducing moisture loss.

Extrusion: Extrusion method is a thermo-mechanical process, mainly used for producing edible films rather than direct fruit coating. In this method, edible polymers are mixed with plasticizers and processed through an extruder, where heat and shear forces melt and shape the material into continuous films or sheets. The extruder films are then cooled, cut and later wrapped around horticultural produce or used as edible packaging.

Spraying: Spraying involves applying the coating solution as a fine mist using hand sprayers or automated spray systems. This allows better control over coating thickness, minimises solution waste and

maintains uniformity. Spraying is widely used for wax coatings on citrus and apples.

Panning: This method is used for small fruits and nuts, where fruits are rotated in a drum while the coating is applied. This method ensures uniform coating and is suitable for berries and dried fruits.

Chemical nature of edible coating materials

Chemically, edible coatings are composed mainly of natural polymers, which can be classified into polysaccharides, proteins, lipids or their composites. Each group has distinct chemical characteristics that determine barrier properties, mechanical strength and functionality. Polysaccharides based edible coatings are composed of long chain carbohydrate polymers containing hydroxyl groups, which impart hydrophilicity and has excellent film-forming ability. Examples include starch, CMC, pectin, alginate, chitosan and plant gums. Protein based edible coatings consists of polypeptide chains linked by peptide bonds and stabilized by hydrogen bonding, disulphide bonds and hydrophobic interaction. Examples include gelatin, casein, whey protein and zein. Lipid-based edible coatings are composed mainly of fatty acids, esters, alcohols, hydrocarbons and waxes. Composite edible coating combines polysaccharides, proteins and lipids to exploit complementary chemical properties.

Unlocking the Secrets of Transgenerational Stress Memory in Plants

Navodhaya J. V., Kingslee S. Sujan and Sakthivel I.

Introduction

The mainstream account of biology has long been comparatively simple: the characteristics of an organism were defined by the sequence of its DNA, and any modifications to such a template were possible only after a long and slow sequence of random mutations over a thousand years. A radical science is however overturning this dogma by disclosing the fact that plants have a complex sort of a cellular journal. They do not simply survive through the times of environmental crisis; they carry the memories with them, and convey those memories to their offspring in order to prepare them to live in the evolving world. It is a phenomenon called transgenerational stress memory and it is more than a biological curiosity. It is one of the pillars of plant survival in the climate change unstable environment, and possibly a holy grail of world food security.

The Rooted Reality: Why Plants Must Remember

In order to know the reasons why plants have developed memory we should start by examining their growing habit. Plants are sessile (they have roots) unlike animals. A plant is unable to run off to a colder forest when a heatwave hits or a wet valley when the water table is drawn down. It needs to hold

its ground and adjust on time. This short-term adjustment is termed as phenotypic plasticity. When a plant is in need of water, it seals its stomata (pores on its leaves) to retain water. In case it is excessively hot, it causes heat shock proteins to safeguard its cellular machineries. However, how does the end of the drought look like? The plant does not simply get back to its original state. It stays "primed." The plant is in a state of readiness similar to that of a soldier who has gone back to patrol after a battle. The really innovative finding of the past two decades is that this preparedness does not perish with the man. It is coded and passed on to the seeds so that the next generation is not beginning afresh.

The Language of Memory: Beyond the Genetic Code

How does a plant inherit a "memory" without having any modification on real DNA sequence? Epigenetics is the solution of the riddle.

Epigenetics is the software to the DNA, which is the hardware of life. It specifies the activated or suppressed genes without modifying the code. Plants encode these epigenetic memos in three major ways:

DNA Methylation: This is where a chemical tag is

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added (methyl group) to the DNA. Imagine a piece of tape on a light switch. The gene remains but the cell is no longer able to turn on the switch to activate the gene.

Histone Modification: DNA is coiled around the proteins known as histones. Through these wraps, a plant can ensure that some genes are easier or harder to read by tightening or loosening these wraps.

Small RNAs: These are small molecules that are capable of targeting and silencing particular genetic instructions before they can be executed.

When a plant is heavily stressed like extreme heat and dry seasons as can be found in the chickpea production, the plant forms a distinct arrangement of the tags. These patterns can be maintained in the case when the plant produces seeds. The children inherit the environments of their parents and they do not have to go through the learning curve and they are obtained to handle stress at an elite level.

The Generation Gap: Intergenerational vs. Transgenerational

When a mother plant is stressed, these seeds are exposed to the stress. This is referred to as intergenerational memory. It is marvellous and yet it is the seed responding to itself within the ovary. The actual transgenerational memory takes place when the memory continues to the F_3 generation (the great-grandchildren). At this stage, the original stressor has never been exposed to the plant and neither were its parents. In case it still shows increased resilience, we understand that the memory is incorporated into the epigenetic heritage of the lineage.

Case Study: The Resilient Chickpea

Use the example of the chickpea (*Cicer arietinum* L.), a major source of protein for millions of people. Chickpeas are usually cultivated in the dry areas where heat and drought are the orders of the day. There is research indicating that a plant of chickpea changes its carbon distribution and root structure in case of drought.

It has been noted that the products of such stressed plants tend to have:

Greater Ground Strength: They develop more deep roots, in search of water which their spoiled brethren could not have discovered.

Transcriptional Priming: their drought-tolerance genes are already unzipped and are in a ready state to be read as soon as the water scarcity is detected.

Metabolic Efficiency: They are more efficient in their energy consumption; that despite the stress, they can still reproduce the nutrient-rich seeds that we depend on as food.

The Evolutionary Gamble

You may ask: why not have memory so great, as to have the plants keep these engines of their defence constantly running?

The reason is metabolic cost. It is costly to be in a high alert-defensive mode. It steals energy that is used to grow tall, create flowers and generate seeds. When a plant is on a recollection of a drought that does not happen, it will be outcompeted by a nearby plant that used all the energy on growth. Transgenerational memory is a balancing act therefore. These memories need to be forgotten or reset by

plants in case the environment is stable and desirable once more. This resetting plays an equally important role just as the remembering in that it entails the avoiding of the plant being stuck with old information.

Feeding a Warming World: The Future of Agriculture

With the rapid change in climate, the number of once-in-a-century weather events occurring every couple of years is increasing. Conventional breeding, which requires us to cross pollinate plants and years later see the fruit, is not faring so well. At this point, the Crisis of stress memory becomes a breakthrough. The next area being investigated by scientists is Epigenetic Breeding. Rather than transforming the DNA, we may also train our crops. Priming Stations: This is a hypothetical scenario where young plants or seeds are primed against future climate shock by exposing them to non-lethal dose of heat or drought.

Chemical Priming: It would be possible to create natural sprays that would activate the memory mechanisms of the plant and place it in a highly resilient state, without necessarily subjecting it to environmental trauma.

Precision Breeding: This is the ability to identify which epigenetic changes result in yield stability, and then plant the seeds that are not only high yielding, but climate-smart.

Conclusion: The Wisdom of the Fields

The discovery of transgenerational stress memory reminds us that plants are not passive victims

of their environment. They are active, sensing, and “intelligent” organisms that curate their experiences for the benefit of their descendants. For a researcher working on a thesis or a farmer looking at a dry field, this science offers a profound sense of hope. It suggests that the resilience we need to survive the 21st century might already be hidden within the plants themselves, waiting to be “unlocked.” The seeds of the future are not just carrying the code for life; they are carrying the wisdom of the past. As we continue to decode the “cellular diaries” of crops like the chickpea, we aren't just learning about biology, we are learning how to build a more resilient world, one generation at a time.

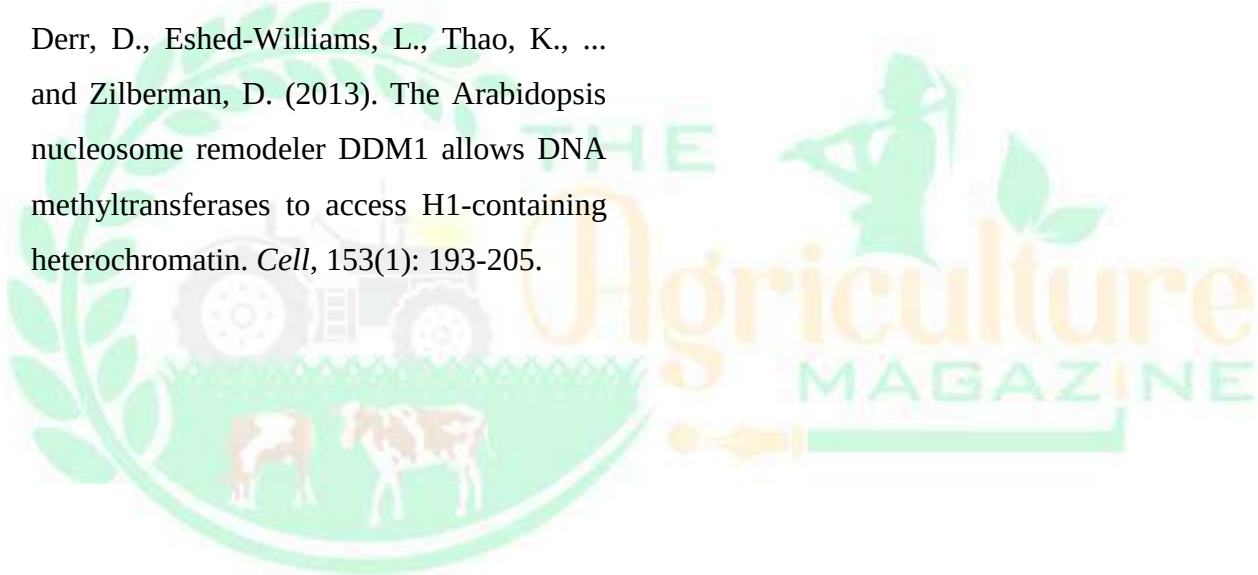
References

- Karalija, E., Vergata, C., Basso, M. F., Negussu, M., Zaccari, M., Grossi-de-Sa, M. F. and Martinelli, F. (2022). Chickpeas' tolerance of drought and heat: Current knowledge and next steps. *Agronomy*, 12(10): 2248.
- Heard, E. and Martienssen, R. A. (2014). Transgenerational epigenetic inheritance: myths and mechanisms. *Cell*, 157(1): 95-109.
- Virdi, K. S., Laurie, J. D., Xu, Y. Z., Yu, J., Shao, M. R., Sanchez, R., ... and Mackenzie, S. A. (2015). Arabidopsis MSH1 mutation alters the epigenome and produces heritable changes in plant growth. *Nature communications*, 6(1): 6386.
- Lyons, D. B. and Zilberman, D. (2017). DDM1 and Lsh remodelers allow methylation of DNA wrapped in nucleosomes. *Elife*, 6: e30674.

Sun, C., Ali, K., Yan, K., Fiaz, S., Dormatey, R., Bi, Z. and Bai, J. (2021). Exploration of epigenetics for improvement of drought and other stress resistance in crops: A review. *Plants*, 10(6): 1226.

Rendina González, A. P., Preite, V., Verhoeven, K. J. and Latzel, V. (2018). Transgenerational effects and epigenetic memory in the clonal plant *Trifolium repens*. *Frontiers in Plant Science*, 9: 1677.

Zemach, A., Kim, M. Y., Hsieh, P. H., Coleman-Derr, D., Eshed-Williams, L., Thao, K., ... and Zilberman, D. (2013). The Arabidopsis nucleosome remodeler DDM1 allows DNA methyltransferases to access H1-containing heterochromatin. *Cell*, 153(1): 193-205.



Phenomics and High-Throughput Phenotyping in Linseed Improvement

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Abstract

Linseed (*Linum usitatissimum*) is an important oilseed crop valued for its rich omega-3 fatty acid content and industrial applications. However, its productivity is constrained by limitations in conventional breeding, particularly inefficient phenotyping of large populations. Phenomics, coupled with high-throughput phenotyping (HTP), provides a powerful solution by enabling rapid, precise, and non-destructive measurement of plant traits (Furbank and Tester, 2011; Araus and Cairns, 2014). This article highlights the application of phenomics in linseed improvement, focusing on yield traits, stress tolerance, and quality enhancement. Advanced tools such as UAV imaging, multispectral sensors, and machine learning are discussed. Despite challenges such as high cost and data complexity, integration with genomics and artificial intelligence offers promising opportunities for future breeding programs (Reynolds *et al.*, 2019).

Introduction

Linseed (*Linum usitatissimum*), also known as flax, is widely cultivated for oil and fibre and is rich in alpha-linolenic acid, an essential omega-3 fatty acid. In India, linseed is mainly grown under rainfed conditions, where productivity is limited by environmental stresses and low genetic gain. Conventional breeding methods rely heavily on manual phenotyping, which is time-consuming, labour-intensive, and prone to human error (Cobb *et al.*, 2013). These limitations become more severe when evaluating large segregating populations such as F₂ and F₃ generations. Therefore, there is a growing need for advanced phenotyping approaches that are rapid, accurate, and scalable. Phenomics has emerged as a key tool to address these challenges by enabling efficient trait measurement and improving

selection accuracy (Araus *et al.*, 2018).

Concept of Phenomics

Phenomics refers to the large-scale study of phenotypes, including morphological, physiological, and biochemical traits of plants. Unlike traditional phenotyping, which focuses on a limited number of traits, phenomics captures high-dimensional data across time and environments (Tardieu *et al.*, 2017). It plays a critical role in linking genotype to phenotype, which is essential for understanding complex traits and improving breeding efficiency. In linseed, phenomics enables the evaluation of important traits such as biomass, plant architecture, and stress tolerance more precisely (Yang *et al.*, 2013).

High-Throughput Phenotyping (HTP)

Definition: High-throughput phenotyping (HTP)

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involves automated and rapid measurement of plant traits using advanced technologies, allowing large-scale screening of breeding populations (Fahlgren *et al.*, 2015). It reduces the phenotyping bottleneck and enhances the speed and efficiency of breeding programs.

Tools and Technologies: HTP systems use advanced tools such as UAVs (drones), multispectral and hyperspectral sensors, thermal imaging cameras, and RGB imaging systems (Araus and Cairns, 2014). These tools allow continuous monitoring of plant growth, stress response, and physiological traits under field conditions. The large datasets generated are analysed using machine learning and image processing techniques to extract meaningful insights (Mir *et al.*, 2019).



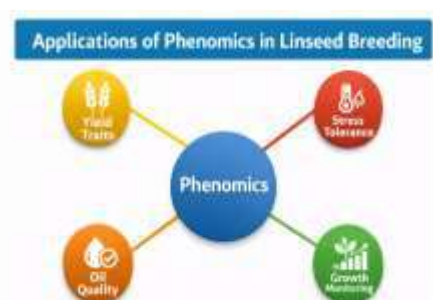
Applications in Linseed Improvement

Yield Trait Improvement: Phenomics enables precise measurement of yield-related traits such as plant height, number of branches, capsules per plant, seed weight, and biomass. Repeated measurements during crop growth provide dynamic insights into plant development and help identify high-yielding genotypes (Reynolds *et al.*, 2019).

Stress Tolerance Breeding: inseed is often exposed to abiotic stresses such as drought and heat. Phenomics tools such as thermal imaging and spectral sensors allow early detection of stress responses and

screening of large germplasm collections efficiently (Araus *et al.*, 2018). This helps in identifying stress-resilient genotypes and developing climate-smart varieties.

Oil Content and Quality Traits: Phenomics facilitates indirect assessment of oil content and seed quality traits through imaging and spectral analysis. It supports the improvement of oil composition, particularly omega-3 fatty acids, which are important for nutritional quality (Mir *et al.*, 2019).



Advantages of Phenomics in Linseed Breeding

Phenomics offers several advantages over conventional phenotyping, including rapid and non-destructive data collection, high accuracy, and the ability to evaluate large populations efficiently (Furbank and Tester, 2011). It also reduces labour requirements and improves selection efficiency, especially in early generations like F_2 and F_3 . Additionally, it enhances the understanding of genotype $\times$ environment interactions, which is crucial for developing stable varieties (Cobb *et al.*, 2013).

Challenges and Limitations

Despite its advantages, phenomics faces several challenges, including high initial investment costs, need for technical expertise, and complexity in data management and analysis (Tardieu *et al.*, 2017).

Moreover, limited access to advanced technologies in developing countries restricts its widespread adoption. Addressing these challenges is essential for integrating phenomics into routine breeding programs.



Future Prospects

The future of linseed improvement lies in integrating phenomics with genomics, artificial intelligence, and precision agriculture tools. Machine learning algorithms can enhance trait prediction and selection accuracy, while IoT-based systems enable real-time monitoring of crop performance (Reynolds *et al.*, 2019). Speed breeding combined with phenomics can further accelerate genetic gain and variety development.



Conclusion

Phenomics and high-throughput phenotyping represent a paradigm shift in linseed breeding by enabling rapid, precise, and large-scale trait evaluation. These technologies significantly improve selection efficiency and genetic gain. Although challenges such as cost and data handling remain,

their integration with modern computational tools offers immense potential for developing high-yielding, stress-tolerant, and nutritionally superior linseed varieties (Araus and Cairns, 2014).

References

- Araus, J. L. and Cairns, J. E. (2014). Field high-throughput phenotyping. *Trends in Plant Science*, 19(1): 52-61.
- Araus, J. L., *et al.* (2018). Translating phenotyping into genetic gain. *Trends in Plant Science*, 23(5): 451-466.
- Cobb, J. N. *et al.* (2013). Next-generation phenotyping. *Plant Science*, 205-206: 1-11.
- Fahlgren, N., *et al.* (2015). High-throughput plant phenotyping. *Current Opinion in Plant Biology*, 24: 93-99.
- Furbank, R. T. and Tester, M. (2011). Phenomics technologies. *Nature Reviews Genetics*, 12: 819-832.
- Mir, R. R. *et al.* (2019). High-throughput phenotyping for crop improvement. *Plant Science*, 282: 60-72.
- Reynolds, M., *et al.* (2019). High-throughput phenotyping. *Journal of Experimental Botany*, 70(17): 4275-4283.
- Tardieu, F., *et al.* (2017). Plant phenomics: from sensors to knowledge. *Current Biology*, 27(15): R770-R783.
- Yang, W., *et al.* (2013). Plant phenomics in crop improvement. *Current Opinion in Plant Biology*, 16(2): 180-187.

Digital Farmer Field Schools in Maharashtra: A New Classroom under the Open Sky

Kaustubh Kadam, Milind Ahire and Manohar Dhadwad

In many parts of Maharashtra, farming is still a daily gamble with the weather. One delayed rain can ruin sowing plans. A sudden pest attack can wipe out months of hard work. Rising input costs, uncertain market prices, and changing climate patterns have made agriculture more challenging than ever. For many farmers, the biggest struggle is not a lack of effort, but a lack of timely information. That is where digital technology is beginning to change the story. Across villages in Maharashtra, a quiet transformation is underway. The traditional image of a farmer learning only from neighboring fields is expanding. Today, farmers are also learning through smartphones, WhatsApp groups, mobile apps, video calls, and online advisory platforms. This new model is often called the Digital Farmer Field School, and it is bringing the classroom directly to the farm.

What is a Digital Farmer Field School?

A Farmer Field School has long been a practical way of teaching farmers. Instead of only sitting in a classroom, farmers learn by observing crops in the field, discussing problems together, and getting guidance from experts. It is hands-on, local,

and based on real farming situations. A Digital Farmer Field School keeps this same spirit, but adds technology to make learning faster, wider, and more accessible. Farmers can receive weather alerts on their phones, join live video sessions with agricultural experts, watch pest management demonstrations online, and share photos of crop diseases for quick advice. In some cases, farmers meet in groups in the village while using a mobile phone or projector to access digital content. In others, they learn individually through apps and voice messages. In simple words, it is a modern extension of the old idea: learning by doing, but with digital support.

How does it work on the ground?

Imagine a group of soybean farmers in a village in Vidarbha. Earlier, if they noticed unusual leaf damage, they might wait days for an extension worker to visit. By then, the damage could spread. In a digital field school model, one farmer can click a photo, send it to a WhatsApp advisory group, and receive guidance from an agricultural officer or scientist within hours. The group can then discuss the advice and act quickly.

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This model usually combines several tools. Mobile phones are the most important. Through them, farmers access short videos, text and voice messages, weather forecasts, market price updates, and crop advisories. Krishi Vigyan Kendras, agricultural universities, NGOs, and farmer groups often support the learning process. Some programs also use village-level facilitators who help less literate farmers understand digital content. The result is a blend of local experience and expert knowledge, delivered in a form that is easier to use in real time.

Why farmers are finding it useful

The biggest strength of Digital Farmer Field Schools is timing. Good farming decisions often depend on getting the right advice at the right moment. If a farmer receives a rainfall warning before spraying, that message can save both money and effort. If pest control advice arrives early, crop losses may be reduced significantly. These programs also make learning more visual and practical. A short video showing how to identify fall armyworm in maize can be far more useful than reading a long pamphlet. A recorded demonstration on drip irrigation maintenance can help farmers revisit the lesson whenever needed. This is especially helpful for small and marginal farmers who cannot easily travel for repeated training sessions. Another major advantage is access. Farmers in remote villages do not always have regular face-to-face contact with scientists or extension staff. Digital platforms can bridge that gap. They can also help women farmers, young agripreneurs and Farmer Producer Organiz-

ation members participate more actively in knowledge sharing. Most importantly, digital learning can lead to better decisions. Better decisions often mean better crop management, reduced losses, improved yields, and in some cases, better incomes.

Stories from Maharashtra's fields

Consider the example of Santosh, a cotton farmer from Yavatmal. After years of depending mainly on pesticide dealers for advice, he joined a village learning group connected to a digital advisory network. During one season, he began receiving regular pest alerts and short videos on integrated pest management. Instead of spraying repeatedly, he learned to identify pest thresholds and use control measures more carefully. By the end of the season, his pesticide costs had come down, and his crop performed better than expected. Then there is Sunita, a vegetable grower from Nashik district. She used her smartphone mostly for family calls until a local training program introduced her to mobile-based farm learning. Soon she was checking weather updates, joining online sessions on disease management, and sharing pictures of her tomato crop with a horticulture expert. What changed most was not just her yield, but her confidence. She was no longer waiting passively for advice; she was seeking it, testing it, and applying it. These may sound like simple changes, but in agriculture, simple changes at the right moment can make a big difference.

The role of government and institutions

The growth of digital agricultural learning in Maharashtra has not happened by accident. Govern-

ment initiatives, agricultural universities, Krishi Vigyan Kendras, ATMA programs, and various development organizations have all played a role in promoting digital extension. Mobile-based advisory systems, SMS alerts, weather information services, online farmer training modules, and app-based platforms have made knowledge more accessible. National and state-level efforts under digital governance and agricultural extension have encouraged farmers to use technology for problem-solving. At the same time, many local institutions have experimented with WhatsApp groups, virtual training sessions, and video-based demonstrations in Marathi and other local languages. This support matters because technology alone is not enough. Farmers need trusted systems, local language content, practical demonstrations, and regular follow-up. When institutions provide these, digital learning becomes far more effective.

The opportunities ahead

Maharashtra has enormous potential to expand Digital Farmer Field Schools. The state has a strong network of agricultural universities, research institutions, extension agencies, and increasingly tech-aware rural youth. If these strengths are connected well, digital learning can become a powerful tool for improving farm productivity and resilience. It can also strengthen Farmer Producer Organizations by helping groups of farmers learn together, plan collectively, and respond more quickly to challenges. Young people in rural areas may find new opportunities as digital facilitators, agri-service

providers, or community trainers. In drought-prone and climate-sensitive regions, digital advisories on water management, crop planning, and weather risks could become especially valuable. In many ways, this is not just about technology. It is about making agricultural knowledge faster, fairer, and closer to the farmer.

But the road is not without hurdles

For all its promise, digital agriculture still faces real obstacles. Internet connectivity remains uneven in many rural areas. Some farmers have smartphones, but not reliable data access. Others share one device within the family. Digital literacy is another challenge, especially for elderly farmers or those who are not comfortable using apps and online tools. Language and usability also matter. If an app is too complex or the advice is not available in a familiar language, farmers may stop using it. Affordability is another concern, because devices, internet packs, and maintenance costs can add up. And perhaps most importantly, farmers need to trust the information they receive. Poor-quality or generic advice can do more harm than good. That is why digital learning should not replace human support. It should strengthen it. The best systems combine technology with local facilitators, extension workers, field demonstrations, and peer discussion.

A hopeful future

The future of farming in Maharashtra will not be built by machines alone. It will be built by informed farmers, practical knowledge, and systems that respond to real needs. Digital Farmer Field

Schools point in that direction. They show that when technology is simple, useful, and locally relevant, it can become a powerful ally in the field. The classroom of the future may not always have walls. It may be a cotton field in Vidarbha, a grape farm in Nashik, or a soybean plot in Marathwada. It may begin with a farmer noticing a problem, opening a phone, and finding the answer in time.

For Maharashtra's farmers, that small moment of connection could be the beginning of a much bigger change.



From Signal to Response: A Molecular Dissection of Signal Transduction Pathways in Living Systems

Kingslee Sujan S., Navodhaya J. V. and Sakthivel I.

Abstract

Signal transduction is a basic process through which cells transform the external signal into a particular response within the cell. This is accomplished with the help of coordinated networks of the protein kinases, second messengers, GTP-binding proteins and adaptor complexes to ensure signal amplification and specificity. Key pathways such as the methylation of protein kinase A (PKA) activation pathway and calcium signaling propagate the signal to the nucleus where various transcription factors regulate the expression of genes. Signal intensity and duration both are tightly controlled by phosphatases and the ubiquitin-proteasome system. In the plant cell, there are additional elements that include the two-component phosphorelay system and hormone specific regulators all refined the signaling outputs. Together, these integrated pathways allow for duplicate responses of cells to environmental and developmental stimuli. This article aims to provide a comprehensive idea of the Signal Transduction Pathways in Living Systems.

Introduction

Signal transduction pathways are the key processes through which cells sense and react to both internal and external signals including hormones, nutrients, light, pathogens and abiotic stresses (Wikipedia contributors, 2026). It starts with the recognition of ligands by particular receptors on the cell surface, and results in cellular responses such as alteration in gene expression, metabolism, growth, and defense (Biology LibreTexts, 2019). On the molecular level, receptors can be activated by the binding of ligands, which leads to intracellular cascades of protein kinases, second messengers, and

GTP- binding proteins that enhance the signal (Revision Dojo, 2025; Fiveable, 2025). These cues are finally sent to the nucleus where they are regulated by the transcription factors to control the expression of the target genes (Whitmarsh and Davis, 1996). Signal transduction is very specialized and tightly controlled by adaptor proteins, scaffold complexes and compartmentalization, and via the mechanisms of phosphatases and protein degradation signal termination is achieved (Bao *et al.*, 2021; Galle *et al.*, 2015). Plants have other mechanisms like the two component phosphorelay system and hormone specific networks which complement

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signal integration more (Hwang *et al.*, 2002).

Protein Kinase Cascades

Protein kinase cascades are key signal amplification mechanisms that transfer phosphate groups from ATP to target proteins (Meng and Zhang, 2013). A classic example is the MAPK cascade (MAPKKK → MAPKK → MAPK), which drives sequential phosphorylation leading to transcriptional activation and downstream responses (Jagodzick *et al.*, 2023).

Key Kinase Families

Calcium, cyclic nucleotide, and stress signal sensory inputs are incorporated by other kinases like CDPKs, SnRKs, PKA, PKC, and CaMKs to regulate cellular functions (Hamann *et al.*, 2023). Due to direct sensing of Ca^{2+} changes and fast phosphorylation of targets, CDPKs can coordinate the response to abiotic stress in plants (Yoo *et al.*, 2023).

Two Component Signaling System (TCS)

The TCS is a two-component system of signaling that is present in plants and bacteria: histidine kinases (HKs) detect signals, histidine phosphotransferase proteins (HPs) exchange phosphate ions, and response regulators (RRs) regulate gene expression (Hwang *et al.*, 2002; Singh *et al.*, 2021; Capra and Laub, 2012). Type-B RRs are activators and Type-A RRs give negative feedback, which results in close regulation of pathways, including cytokinin signaling (Mason *et al.*, 2005; Kiba *et al.*, 2013).

Second Messengers: Jackpot Signal Multipliers

Small diffusible molecules are also second messengers, including cAMP, cGMP, Ca^{2+} , IP₃, DAG, ROS and NO, which are quickly diffused to several intracellular targets (Newton *et al.*, 2015; Sami *et al.*, 2019). An example is the amplification of signals and diversity of pathways such as IP₃-mediated Ca^{2+} release and cAMP activation of PKA (Tuteja and Tuteja, 2007).

Proteins That Bind GTP: Molecular Switches

The GTP-binding proteins are molecular switches, which switch between the active (GTP-bound) and inactive (GDP-bound) forms (Jones and Temesvari, 2019). The receptor signals are relayed to the effector enzymes by heterotrimeric G-proteins, and small GTPases including RAS, RHO/ROP, RAB, and ARF mediate the activation of the kinases, organization of cytoskeleton, and vesicle trafficking (Urano *et al.*, 2012; Yalovsky *et al.*, 2017).

Adaptor and Scaffold Proteins

GRB2, SOS and Shc are adaptor proteins that connect receptors to the downstream molecules such as RAS (Kolch, 2005). KSR scaffold proteins are involved in organizing the kinase cascades, 14-3-3 proteins are involved in the regulation of protein stability and localization, and plants NLR develop immune signaling complexes (Roy *et al.*, 2002; Bommert *et al.*, 2011; Maekawa *et al.*, 2011).

Phosphatases: Signal Modulators

Phosphatases neutralize the effects of kinases to control and stop signaling (Hunter, 1995). The dephosphorylation of proteins occurs via the activity of enzymes, including PP1, PP2A, and PP2C which

eliminate phosphate groups and MAPK phosphatases (MKPs) which inactivate MAPKs and PTEN which controls lipid signaling by converting PIP3 into PIP2 (Barford, 1996; Keyse, 2000; Cantley and Neel, 1999).

Lipid-Derived Signaling Molecules

Lipid membrane molecules are important in the production and transmission of signals (Carrasco and Merida, 2007). PIP2 acts as a precursor of IP3 and DAG, PIP3 interacts with proteins such as AKT, and phosphatidic acid (PA) is a stress-responsive signaling molecule in plants (Berridge, 2016; Engelman *et al.*, 2006; Testerink and Munnik, 2011).

Calcium Decoders and Sensors

Sensor proteins that perceive calcium signals include calmodulin (CaM) and CBL-CIPK complexes of plants (Sanders *et al.*, 2002). Such proteins convert temporary Ca^{2+} spikes into definite biochemical reactions, which regulate such processes as ion transport, stress adaptation, and gene expression (Kudla *et al.*, 2010).

Transcription Factor: Final Effectors

Activation of transcription factors, such as CREB, MYC /MYB, WRKY, bZIP, NAC, NF- κ B, AP2/ERF, and STAT, is the final result of signaling cascades (Singh *et al.*, 2002). The factors control the patterns of gene expression dictating the cell response which may be growth, defense or adaptation to stress (Nuruzzaman *et al.*, 2010).

Ubiquitin-Proteasome System

Signaling is a crucial regulatory process which involves protein degradation (Vierstra, 2009).

The interplay of E1, E2 and E3 ubiquitin ligases, and 26S proteasome, is what helps maintain selective degradation of important regulatory proteins (Smalle and Vierstra, 2004). The SCF complex is very essential in the process of hormone signaling as it targets repressors to be degraded (Gray *et al.*, 2001).

Hormone-Specific Regulators of Plants

Specialized components of plant signaling pathways are DELLA proteins (GA signaling repressors), EIN2/EIN3 (ethylene signaling regulators), ABI1/ABI2 (ABA pathway phosphatases), and NPR1 (salicylic acid-mediated defense regulator) (Santner *et al.*, 2009). These components combine the hormonal signals with the environmental signals in order to streamline the plant responses (Gray, 2004).

Conclusion

Signal transduction is a highly sophisticated and interconnected network that enables cells to respond with remarkable precision and adaptability. Through coordinated action of kinases, second messengers, molecular switches, and transcription factors, cells achieve both amplification and specificity in their responses. In plants, the integration of conserved eukaryotic signaling mechanisms with unique systems such as the two-component phosphorelay underscores the evolutionary diversification of signaling networks. A deeper understanding of these pathways holds immense potential for applications in crop improvement, stress resilience and biotechnology, making signal transduction a central theme in modern biological research.

References

- Bao, F., *et al.* (2021). Akt scaffold proteins: The key to controlling specificity of Akt signaling in cancer. *American Journal of Physiology-Cell Physiology*, 321(4): C571-C585.
- Barford, D. (1996). Protein phosphatases: Structures and regulation. *Trends in Biochemical Sciences*, 21(1): 11-16.
- Berridge, M. J. (2016). The inositol trisphosphate/calcium signaling pathway in health and disease. *Physiological Reviews*, 96(4): 1261-1296.
- Biology LibreTexts. (2019). Signal transduction. https://bio.libretexts.org/Learning_Objects/Worksheets/Biology_Tutorials/Signal_Transductionbio.libretexts
- Bommert, P., *et al.* (2011). The 14-3-3 protein interacts with the receptor-like kinase CLV1 to regulate shoot apical meristem development in Arabidopsis. *Plant Cell*, 23(3): 1077-1092.
- Cantley, L. C. and Neel, B. G. (1999). New insights into tumor suppression: PTEN suppresses tumor formation by restraining the phosphoinositide 3-kinase/AKT pathway. *Proceeding of the National Academy of Sciences*, 96(8): 4240-4245.
- Engelman, J. A., Luo, J. and Cantley, L. C. (2006). The evolution of phosphatidylinositol 3-kinases as regulators of growth and metabolism. *Nature Reviews Genetics*, 7(8), 606-619.
- Capra, E. J. and Laub, M. T. (2012). Evolution of two-component signal transduction systems. *Annual Review of Microbiology*, 66: 325-347.
- Carrasco, S. and Mérida, I. (2007). Diacylglycerol kinase: At the hub of cell signaling. *Progress in Lipid Research*, 46(5): 263-285.
- Fiveable. (2025). Introduction to signal transduction - AP Bio study guide. <https://fiveable.me/ap-bio/unit-4/intro-signal-transduction/study-guide/VAotQCiNsYQzCcmUBt3Dfiveable>
- Galle, A., *et al.* (2015). Targeting proteins for proteasomal degradation-A new strategy for crop improvement. *Frontiers in Plant Science*, 6: 310.
- Gray, W. M., Kepinski, S., Rouse, D., Leyser, O. and Estelle, M. (2001). Auxin regulates SCF^{TIR1}-dependent degradation of AUX/IAA proteins. *Nature*, 414(6861): 271-276.
- Hamann, T., *et al.* (2023). Calcium-dependent protein kinases in plants. *Plants (Basel)*, 12(4): 840.
- Hunter, T. (1995). Protein kinases and phosphatases: The yin and yang of protein phosphorylation and signaling. *Cell*, 80(2): 225-236.
- Sami, F., Yusuf, M., Dhamanage, M. K., Ahmad, A. and Qureshi, M. I. (2019). Effect of chronic water stress and elevated temperature on morphology, physiology, and secondary metabolites of *Withania somnifera* (L.) Dunal. *Protoplasma*, 256(6): 1601-1616.

- Hwang, I., Chen, H.-C. and Sheen, J. (2002). Two-component signal transduction pathways in Arabidopsis. *Plant Physiology*, 129(2): 500-515.
- Jagodzik, P., et al. (2023). MAPKKs in plants: Multidimensional regulators of growth, metabolism and stress responses. *International Journal of Molecular Sciences*, 24(4): 3960.
- Jones, J. D. and Temesvari, L. A. (2019). The diverse roles of small GTPases in intracellular trafficking. *International Journal of Molecular Sciences*, 20(22): 5576.
- Keyse, S. M. (2000). Dual-specificity MAP kinase phosphatases (MKPs) and stress signal transduction. *Trends in Biochemical Sciences*, 25(12): 599-605.
- Kiba, T., Takei, K., Krall, L. and Sakakibara, H. (2013). Nitrate-induced control of cytokinin signaling pathway in Arabidopsis. *Plant Signaling & Behavior*, 8(10): e26019.
- Kolch, W. (2005). Coordinating ERK/MAPK signalling through scaffolds and inhibitors. *Nature Reviews Molecular Cell Biology*, 6 (11): 827-837.
- Kudla, J., Batistič, O. and Hashimoto, K. (2010). Calcium signals: The lead currency of plant information processing. *The Plant Cell*, 22 (3): 541-563.
- Smalle, J. and Vierstra, R. D. (2004). The ubiquitin 26S proteasome proteolytic pathway. *Annual Review of Plant Biology*, 55: 555-590.
- Maekawa, T., Kracher, B., Vernaldi, S., van Themaat, E. V. L. and Schulze-Lefert, P. (2011). Conservation of NLR immune sensor system signaling between monocots and dicots. *Proceedings of the National Academy of Sciences*, 108(33): 13811-13816.
- Mason, M. G., Mathews, D. E., Argyros, D. A., Maxwell, B. B., Kieber, J. J., Alonso, J. M., Ecker, J. R. and Schaller, G. E. (2005). Multiple type-B response regulators mediate cytokinin signal transduction in Arabidopsis. *The Plant Cell*, 17(12): 3007-3017.
- Meng, P.-H. and Zhang, S. (2013). Conveying endogenous and exogenous signals: MAPK cascades in plant growth and defense. *Current Opinion in Plant Biology*, 16(5): 635-642.
- Newton, A. C., Broekman, M. J. and Maudsley, S. (2015). Protein kinase C. *Cold Spring Harbor Perspectives in Biology*, 7(10): a021156.
- Nuruzzaman, M., Manimekalai, R., Sharoni, A. M., Satoh, K. and Kikuchi, S. (2010). NAC transcription factor family genes in rice and their genome-wide expression analysis. *Plant Biotechnology*, 27(4): 269-278.
- Sanders, D., Pelloux, J., Brownlee, C. and Harper, J. F. (2002). Calcium at the crossroads of signaling. *The Plant Cell*, 14(suppl_1): S401
- Wikipedia contributors. (2026). Signal transduction. *Wikipedia*. https://en.wikipedia.org/wiki/Signal_transductionwikipedia

- Revision Dojo. (2025). How ligand-receptor interactions trigger intracellular signalling cascades. <https://www.revisiondojo.com/blog/how-ligand-receptor-interactions-trigger-intracellular-signalling-cascades>revisiondojo
- Roy, F., Laberge, G., Douziech, M., Ferland-McCollough, D. and Therrien, J. (2002). KSR is a scaffold required for activation of the ERK/MAPK module. *Genes & Development*, 16(13): 1722-1732.
- Singh, D., Yadav, N. S., Reddy, C. E. S. and Singh, J. (2021). The journey from two-step His-Asp to multi-step phosphorelay signaling in plants. *Frontiers in Plant Science*, 12: 626650.
- Singh, K. B., Foley, R. C. and Oñate-Sánchez, L. (2002). Transcription factors in plant defense and stress responses. *Current Opinion in Plant Biology*, 5(5): 430-436.
- Testerink, C. and Munnik, T. (2011). Molecular mechanisms of plant phosphatidic acid-mediated stress signaling. *Trends in Plant Science*, 16(10): 540-546.
- Urano, D., Jones, A. M. and Nielsen, G. L. (2012). Analysis of Gα protein heterotrimer dynamics in plant cells. *Plant Signaling & Behavior*, 7(10): 1345-1351.
- Vierstra, R. D. (2009). The ubiquitin-26S proteasome system at the nexus of plant biology. *Nature Reviews Molecular Cell Biology*, 10(6): 385-397.
- Whitmarsh, A. J. and Davis, R. J. (1996). Control of transcription factors by signal transduction pathways: The beginning of the end. *Trends in Biochemical Sciences*, 17(9): 357-362.
- Yalovsky, S., Bloch, D., Sorek, N. and Kost, B. (2017). Regulation of membrane trafficking, cytoskeletal structures and signaling by ROP/RAC GTPases in plants. *Biochemical Journal*, 415(1): 229-249.
- Yoo, Y., et al. (2023). Comprehensive analysis of the CDPK-SnRK superfamily reveals their roles in growth, development, and stress response in pear (*Pyrus bretschneideri*). *BMC Plant Biology*, 23: Article 162

Diversity and Evolutionary Trajectories of Chilli Leaf Curl Virus

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Abstract

Chilli leaf curl virus (ChiLCV; genus *Begomovirus*, family *Geminiviridae*) is a predominantly monopartite circular ssDNA virus responsible for severe leaf curl disease in *Capsicum* spp., by causing yield losses up to 100% in tropical and subtropical regions. Recent studies have revealed that ChiLCD is not caused by a single viral entity but involves a complex of genetically diverse begomoviruses and associated satellite molecules. Its evolutionary trajectories are shaped by high mutation rates, frequent recombination, associations with satellite molecules (ChiLCA and ChiLCB), and a balance of purifying and diversifying selection pressures. Phylogenetic studies of over 130 isolates reveal 3-4 major clades with geographic mixing and reticulate evolution. Nucleotide substitution rates (comparable to those of RNA viruses) facilitate rapid adaptation, host-range expansion, and emergence of virulent strains, often through mixed infections.

Introduction

ChiLCV are the largest genus of plant viruses many of which are monopartite in the Old World. It was first prominently linked to chilli in India, exemplifies rapid viral emergence in solanaceous crops. It is transmitted persistently by the whitefly *Bemisia tabaci* and induces upward leaf curling, crinkling, vein thickening, stunting, and fruit deformation. The virus is widespread across Asia (with India as a major hotspot), the Middle East, and parts of Africa, driven by intensive cultivation and vector polyphagy (Misra *et al.*, 2022). Evolutionary success arises from its compact genome with overlapping ORFs, error-prone rolling-circle replication and frequent intra- and inter-species recombination enabled by mixed infections. Associated satellites (α -satellites for replication support and β -

satellites for virulence enhancement via β C1) further boost pathogenicity and adaptability.

Genome organization: ChiLCV is a distinct begomovirus species (ICTV threshold: <89% DNA-A nucleotide identity). Its ~2.7 kb circular ssDNA genome encodes 6–7 ORFs: virion-sense (V1/CP coat protein; V2) and complementary-sense (C1/AC1 Rep; C2/AC2 TrAP; C3/AC3 RE; C4). The intergenic region (IR) contains the origin of replication with a stem-loop and iterons. Most isolates are monopartite with a β -satellite; DNA-B and α -satellite associations occur less frequently.

Phylogenetic Diversity and Geographical Patterns: Analyses of 132 ChiLCV DNA-A sequences cluster isolates into three major clades, reflecting geographic structuring with some mixing: Clade I (predominantly Oman), Clade II (India/Pakistan with

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extensions to Bangladesh, Sri Lanka, Korea), and Clade III (Pakistan/India). High nucleotide diversity ($\pi = 0.10769$) and 113 haplotypes indicate substantial population variation (Misra *et al.*, 2022). Indian isolates often resolve into four phylogenetic groups involving ChiLCV, PepLCBV, ToLCV, and ToLCNDV, with β -satellites forming five clades and α -satellites showing reticulated networks. Additional studies with 83–84 isolates confirm 14 clades and close relationships between ChiLCV, ChiLCAV, and related viruses like ChiLCMuV or PaLCuV. Reticulation and host/geographic mixing point to ongoing gene flow via whiteflies and trade (Pandey *et al.*, 2022 and Shingote *et al.*, 2022). Distinct begomovirus species and strains have been identified in northern, southern, and central India, indicating geographical structuring of viral populations. Such diversity complicates the development of universally resistant chilli varieties.

Mechanisms Driving Evolutionary Trajectories

Mutation and Nucleotide Diversity: High mutation counts are observed across the genome: ~2104-2505 for DNA-A (highest in Rep/TrAP), ~1070-1288 for β -satellites. Nucleotide diversity (π) peaks in C4 (~0.1837) and Rep (~0.1752) regions. Transition/transversion bias (R) is ~1.07 for DNA-A, with maxima in CP (1.59) (Pandey *et al.*, 2022; Misra *et al.*, 2022).

Recombination: Recombination is a primary driver, with 49-51 breakpoints detected in DNA-A (hotspots in V1/CP, C1/Rep up to 22 events and C2/C4). β -satellites also show significant events, often in A-

rich or SCR regions. Inter-species recombination and pseudo-recombination in mixed infections generate novel virulent strains, contributing to reticulate phylogenetic networks (Misra *et al.*, 2022).

Selection Pressure and Substitution Rates: dN/dS ratios indicate overall purifying selection on core genes (Rep, REn) but diversifying pressure on CP and symptom determinants. Negative Tajima's D and Fu & Li's D* values suggest population expansion and excess rare variants under purifying selection. Estimated substitution rates for DNA-A fall in the range of $2.4-5.3 \times 10^{-3}$ substitutions/site/year (relaxed molecular clock), overlapping RNA virus rates and enabling rapid adaptation. Satellite molecules act as evolutionary accelerators by modulating virulence and host interactions (Misra *et al.*, 2022).

Adaptive Implications

These mechanisms support host-range expansion (tomato, papaya, weeds), resistance-breaking, and enhanced vector transmission. Mixed infections with other begomoviruses or phytoplasmas increase severity and drive further diversification, amplified by climate change and agricultural practices.

Conclusion

Chilli leaf curl disease in India is a complex pathosystem driven by a highly diverse population of begomoviruses and their associated satellites. The frequent occurrence of mixed infections further enhances disease severity and accelerates viral evolution. Addressing this challenge requires a comprehensive understanding of virus diversity, host

interactions, and epidemiological factors. Future research should focus on genomic surveillance, resistance breeding and integrated disease management to mitigate the impact of ChiLCD on chilli production.

References

- Mishra, M., Verma, R. K., Pandey, V., Srivastava, A., Sharma, P., Gaur, R. and Ali, A. (2022). Role of diversity and recombination in the emergence of chilli leaf curl virus. *Pathogens*, 11(5): 529.
- Pandey, V., Srivastava, A., Mishra, M. and Gaur, R. K. (2022). Chilli leaf curl disease populations in India are highly recombinant, and rapidly segregated. *3 Biotech*, 12(3): 83.
- Shingote, P. R., Wasule, D. L., Parma, V. S., Holkar, S. K., Karkute, S. G., Parlawar, N. D. and Senanayake, D. M. J. B. (2022). An overview of chili leaf curl disease: Molecular mechanisms, impact, challenges and disease management strategies in Indian subcontinent. *Frontiers in Microbiology*, 13: 899512.
- Shahid, M. S., Shafiq, M., Raza, A., Al-Sadi, A. M. and Briddon, R. W. (2019). Molecular and biological characterization of Chilli leaf curl virus and associated Tomato leaf curl beta-satellite infecting tobacco in Oman. *Virology Journal*, 16(1): 131.

Fish Collagen: Nature's Marine Protein

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Introduction

A substantial amount of fishery resources is either lost or utilised to manufacture low-value fish meal and oil during processing (Subhan *et al.*, 2020). Typically, the fish processing industry uses only 25%, with the remaining 75% considered waste byproducts (Gaikwad *et al.*, 2024). The discarded section provides a rich source of important proteins, including collagen, as well as vitamins, minerals, and other bioactive compounds (Subhan *et al.*, 2020). According to Pallela *et al.* (2013), the most common and expensive commercial sources of collagen are pig skin, pork, bovine hide, cow bones, and other animal sources. Furthermore, some religions, including Sikhs and Hindus, forbid the use of products derived from cows and pigs (Kittiphattanabawon *et al.*, 2019). As an alternative, various research has been conducted on fish collagen in recent years. After structural alteration, fish collagen exhibits comparable properties to collagen obtained from terrestrial animals (Zhang *et al.*, 2020). This article presents a comprehensive review of the collagen from fish byproducts and their diverse applications.

Fish collagen: The amount of fish waste produced is rising every year due to the expanding global population and consumption. As a result, it is critical to research the potential to utilise industrial waste and fish by-products (Nagai and Suzuki, 2000; FAO,

2002). Fish waste can be used for a variety of applications, including animal feed, food packaging (chitosan), biodiesel/biogas, dietetic products (chitosan), natural pigments (after extraction), soil fertilizer, enzyme isolation, moisture maintenance in foods (hydrolysates), and, most importantly, as a sustainable and alternative source of fish collagen (Arvanitoyannis and Kassaveti, 2008). Collagen is a component of the fibrous structural protein in the extracellular matrix and connective tissue, as well as the basis of bones, tendons, skin, hair, nails, cartilage, and joints (Tiwari *et al.*, 2023). Fish collagen has gained popularity among biomedical researchers due to its superior physicochemical qualities, stability, mechanical strength, biocompatibility and degradability (Subhan *et al.*, 2020). Collagen is found in a variety of marine organisms, including fish (Pisces), jellyfish (Cnidaria), sponges (Porifera), molluscs (octopus, mussel, cuttlefish, and squid), and certain echinoderm species (Pallela *et al.*, 2013).



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Fish byproducts that can be utilised as sources of collagen include skin, scales, bones, skull, swimming bladder, and residual viscera. Among all fish byproducts, skin is the most effective source of fish collagen extraction (Rajabimashhadi *et al.*, 2023). Fish contains type I collagen, which is the most prevalent protein in the human body. Type I collagen has multiple applications, including anti-inflammation, skin beauty, strong connective tissue, and bone strength (Subhan *et al.*, 2017; Katsnelson, 2015).



Source: Rajabimashhadi *et al.*, 2023

Application of Fish Collagen

Biomedical applications of fish collagen: Collagen's superior biocompatibility, low antigenicity, high biodegradability, favourable mechanical, haemostatic and cell-binding qualities make it a perfect material for tissue engineering applications (Dong and Lv 2016; Pati *et al.*, 2012). Collagen derived from fish has been widely used in numerous tissue engineering applications, including the regeneration of skin, bone, and cartilage (Gaikwad *et al.*, 2024). Collagen hydrogels are often regarded as the most effective wound dressings due to their capacity to self-arrange and cross-link, resulting in stable and strong fibres (Shalaby *et al.*, 2020). The utilisation of

polymeric matrix, fish collagen nanoparticles, and micro-particles for drug delivery applications is receiving greater consideration (Felician *et al.*, 2018). For this purpose, collagen from the marine sponges, jellyfish, was evaluated for the drug delivery potential (Felician *et al.*, 2018).

Food Applications of Fish Collagen: Collagen has been used to prepare a variety of goods, including meat products, drinks, soups, and others (Wang *et al.*, 2018). Collagen also acts as a food additive that is added to food while processing in order to improve the taste, colour, or flavour (Gaikwad *et al.*, 2024). Collagen protein can be purified and employed in processed meat products to enhance protein functionality by immobilising free water and boosting product stability (Prabhu *et al.*, 2004). Collagen supplements also help to decrease injury recovery time, boost muscle gain, and reconstruct damaged joints (Zhang *et al.*, 2008). Collagen has been used to prepare a variety of goods, including meat products, drinks, soups and others (Wang *et al.*, 2018).

Collagen in Cosmetics: Collagen plays a crucial role in the body because it supports the skin, which is the largest organ in the human body (Wang *et al.*, 2018). According to research, fish collagen can retain water and absorb moisture, which may have anti-ageing effects on the skin and be utilised as an active component in skin care products (Kim *et al.*, 2018). Collagen peptides include antioxidant properties that aid in safeguarding the skin against free radicals and counteracting their ageing effects

(Sibilla *et al.*, 2015).

Conclusions

Marine resources, particularly fish waste, provide a cost-effective, large-scale supply of fish collagen for diverse applications. Fish processing by-products are a reliable and cost-effective source of collagen. Collagen derived from fish waste is highly biocompatible and biodegradable, making it ideal for a variety of uses. This article gives a comprehensive introduction to collagen, its properties, and applications in a range of industries, with a focus on fisheries and aquaculture sources.

References

- Arvanitoyannis, I. S. and A. Kassaveti. (2008). Fish industry waste: Treatments, environmental impacts, current and potential uses. *International Journal of Food Science & Technology*, 43(4): 726-45.
- Dong, C. and Y. Lv. (2016). Application of collagen scaffold in tissue engineering: Recent advances and new perspectives. *Polymers*, 8 (2): 1-20.
- FAO. (2002). World Fishery Production, Rome, FAO Fisheries Department.
- Felician, F. F., C. Xia, W. Qi, and H. Xu. (2018). Collagen from marine biological sources and medical. *Chemistry & Biodiversity*, 15(5): e1700557.
- Gaikwad, S. and Kim, M. J. (2024). Fish by-product collagen extraction using different methods and their application. *Marine Drugs*, 22(2): 60.
- Kim, D. U., Chung, H. C., Choi, J., Sakai, Y. and Lee, B. Y. (2018). Oral Intake of Low-Molecular-Weight Collagen Peptide Improves Hydration, Elasticity, and Wrinkling in Human Skin: A Randomized, Double-Blind, Placebo-Controlled Study. *Nutrients*, 10: 826.
- Kittiphattanabawon, P., Sriket, C., Kishimura, H. and Benjakul, S. (2019). Characteristics of acid and pepsin solubilized collagens from Nile tilapia (*Oreochromis niloticus*) scale. *Emirates Journal of Food Agriculture*, 31: 95-101.
- Nagai, T. and N. Suzuki. (2000). Isolation of collagen from fish waste material-skin, bone and fins. *Food Chemistry*, 68(3): 277-81.
- Pallela, R., J. Venkatesan, I. Bhatnagar, Y. Shim and S. Kim. (2013). Applications of marine collagen-based scaffolds in bone tissue engineering. In *Marine Biomaterials: characterization, Isolation and Applications*, 519-28. Florida, USA: CRC press.
- Pati, F., P. Datta, B. Adhikari, S. Dhara, K. Ghosh, and P. K. D. Mohapatra. (2012). Collagen scaffolds derived from fresh water fish origin and their biocompatibility. *Journal of Biomedical Materials Research Part A*, 100 (4): 1068-79.
- Rajabimashhadi, Z., Gallo, N., Salvatore, L. and Lionetto, F. (2023). Collagen derived from fish industry waste: progresses and challenges. *Polymers*, 15(3): 544.

- Katsnelson, A. (2015). Cosmetics: Molecular beauty. *Nature*, 526(7572): S4-S5.
- Shalaby, M., Agwa, M., Saeed, H., Khedr, S. M., Morsy, O. and El-Demellawy, M. A. (2020). Fish scale collagen preparation, characterization and its application in wound healing. *Journal of Polymer Environment*, 28: 166-178.
- Sibilla, S., Godfrey, M., Brewer, S., Budh-Raja, A. and Genovese, L. (2015). An overview of the beneficial effects of hydrolysed collagen as a nutraceutical on skin properties: Scientific background and clinical studies. *Open Nutraceuticals Journal*, 8: 29-42.
- Subhan, F., H. Y. Kang, Y. Lim, M. Ikram, S. Y. Baek, S. Jin, and S. Yoon, S. (2017). Fish scale collagen peptides protect against CoCl₂/ TNF- α -induced cytotoxicity and inflammation via inhibition of ROS, MAPK, and NF- κ B pathways in HaCaT cells. *Oxidative Medicine and Cellular Longevity*, 2017: 1-17.
- Subhan, F., Hussain, Z., Tauseef, I., Shehzad, A. and Wahid, F. (2021). A review on recent advances and applications of fish collagen. *Critical Reviews in Food Science and Nutrition*, 61(6): 1027-1037.
- Zhang X., Xu S., Shen L. and Li G. (2020). Factors affecting the thermal stability of collagen from the perspectives of extraction, processing and modification. *Journal of Leather Science and Engineering*, 2: 19.
- Tang, C., Zhou, K., Zhu, Y., Zhang, W., Xie, Y., Wang, Z., Zhou, H., Yang, T., Zhang, Q. and Xu, B. (2022). Collagen and its derivatives: From structure and properties to their applications in food industry. *Food Hydrocoll*, 131: 107748.
- Tiwari, R., Mishra, J., Devhare, L. D. and Tiwari, G. (2023). An updated review on recent developments and applications of fish collagen. *Pharma Times*, 55(6): 28-36.
- Wang, J., Pei, X., Liu, H. and Zhou, D. (2018). Extraction and characterisation of acid-soluble and pepsin-soluble collagen from skin of loach (*Misgurnus anguillicaudatus*). *International Journal of Biological Macromol.*, 106: 544-550.
- Zhang, L. L., Wei, W., Xiao, F., Xu, J. H., Bao, C. D., Ni, L. Q. and Li, X. F. (2008). A randomised, double-blind, multicenter, controlled clinical trial of chicken type II collagen in patients with rheumatoid arthritis. *Arthritis Care Res. Off. Journal of American Coll. Rheumatol.*, 59: 905-910.

Phytoremediation Potential of Aquatic Macrophytes

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Abstract

Macrophytes are aquatic plants that offer an efficient, low-cost solution for water remediation through phytoremediation processes. They remove pollutants such as excess nutrients, heavy metals, and organic contaminants via mechanisms including phytoextraction, rhizofiltration, and microbial interactions in the root zone. Species like *Eichhornia crassipes*, *Lemna minor*, and *Typha* are widely used in constructed wetlands, aquaculture effluent treatment, and lake restoration. In the Indian context, macrophytes are highly relevant due to their adaptability to tropical conditions and suitability for decentralized wastewater treatment. Despite challenges like biomass management and invasive-ness, they provide a sustainable approach for improving water quality and supporting ecological restoration.

Introduction

Aquatic pollution has emerged as a critical environmental challenge in India due to rapid urbanization, industrial discharge, agricultural runoff, and unregulated waste disposal. Conventional wastewater treatment technologies, although effective, are often capital-intensive, energy-demanding, and difficult to implement in decentralized or rural settings. This has led to increasing interest in nature-based solutions, particularly the use of aquatic plants macrophytes for environmental remediation. Macrophytes are large, visible aquatic plants that grow in or near water bodies and include floating, submerged, and emergent forms. These plants play a crucial ecological role in aquatic ecosystems by regulating nutrient cycles, providing habitat, and maintaining water quality. Their ability to absorb, accumulate, transform, and stabilize contaminants makes them highly suitable agents for phytoremedia-

tion, a sustainable and eco-friendly approach to pollution control. In remediation systems, macrophytes function through a combination of biological uptake, rhizospheric microbial interactions, and physicochemical processes. They can effectively remove excess nutrients such as nitrogen and phosphorus, thereby controlling eutrophication, as well as accumulate toxic heavy metals like cadmium, lead, and chromium from contaminated water. Additionally, they contribute to the degradation of organic pollutants, including pesticides and industrial chemicals, through enzymatic and microbial pathways associated with their root zones. The relevance of macrophyte-based remediation is particularly significant in the Indian context. With a large number of polluted rivers, eutrophic lakes, and expanding aquaculture systems, there is an urgent need for cost-effective, scalable, and sustainable treatment technologies. Macrophytes offer a viable

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solution due to their low operational costs, minimal energy requirements, and adaptability to tropical climatic conditions, which support high biomass productivity throughout the year. Thus, macrophytes represent a promising intersection of ecology and engineering, serving as natural biofilters that can be integrated into wastewater treatment systems, aquaculture practices, and ecosystem restoration strategies. Their application not only improves water quality but also supports circular bioeconomy approaches through biomass reuse, making them an important tool for sustainable environmental management in India.

Mechanisms of Remediation

Macrophytes operate through multiple biochemical and physicochemical pathways for remediation. Phytoextraction involves the uptake of heavy metals such as Cd, Pb, Hg, and Cr into plant tissues, with *Eichhornia* known to accumulate Pb and Cd efficiently. This process depends on the plant's biomass production and metal tolerance capacity, allowing contaminants to be concentrated in harvestable parts. Rhizofiltration refers to the adsorption of pollutants from the water column by plant roots and is important in industrial effluent polishing, where extensive root systems provide a large surface area for binding contaminants. Phytodegradation involves the breakdown of organic pollutants such as pesticides and hydrocarbons, mediated by plant enzymes and rhizospheric microbes, enhancing degradation efficiency through synergistic interactions. Phytostabilization includes

the immobilization of contaminants in sediments, preventing their leaching and reducing bioavailability, thus limiting their movement through aquatic systems. Additionally, macrophytes contribute to nutrient removal by absorbing nitrogen and phosphorus, thereby reducing eutrophication and controlling algal blooms, which helps in maintaining ecological balance and improving overall water quality.

Why Macrophytes are Highly Relevant?

Macrophytes are highly relevant to India due to the country's unique environmental challenges and the need for cost-effective, scalable remediation technologies. Indian water bodies are increasingly subjected to high nutrient loading, particularly in major river systems such as the Ganga and Yamuna, primarily due to untreated sewage and agricultural runoff. This leads to eutrophication, resulting in algal blooms and deterioration of water quality. Additionally, the presence of dense industrial clusters contributes significantly to heavy metal contamination, with pollutants such as chromium, lead, and cadmium being discharged into aquatic systems. Aquaculture activities, which are rapidly expanding across states like Andhra Pradesh and West Bengal, also generate nutrient-rich effluents that require efficient management to prevent environmental degradation.

In this context, macrophytes offer several advantages that make them particularly suitable for Indian conditions. They provide a low-cost and low-energy alternative to conventional wastewater treat-

ment systems, making them accessible for widespread implementation, especially in resource-limited settings. Their application is highly suitable for rural and peri-urban areas where centralized treatment infrastructure is often lacking. Furthermore, India's tropical climate supports rapid growth and high biomass productivity of macrophytes throughout most of the year, enhancing their efficiency in pollutant removal. Beyond these factors, macrophyte-based systems can be easily integrated into decentralized treatment models, such as constructed wetlands and farm-level wastewater management units. They also support additional benefits like carbon sequestration, habitat provision, and biomass generation that can be reused as compost or animal feed. This aligns well with sustainable and circular bioeconomy approaches being promoted in India. Therefore, macrophytes represent a practical and environmentally sound solution for addressing diverse water pollution challenges while ensuring adaptability, affordability, and ecological compatibility across different regions of the country.



Fig. 1: Common species of macrophytes in India

Practical Applications in the Indian Scenario

Macrophytes have been widely applied in India for the remediation of diverse aquatic pollution sources through practical and scalable approaches. One of the most prominent applications is in constructed wetlands, where plants such as Typha and Phragmites are used for decentralized sewage treatment in rural and peri-urban areas. These systems effectively reduce biochemical oxygen demand (BOD), nutrients, and suspended solids, and are being implemented under river conservation initiatives. In aquaculture, floating macrophytes like *Lemna minor* and *Azolla* are utilised to treat nutrient-rich effluents by absorbing excess nitrogen and phosphorus, while also serving as a supplementary protein source for fish feed, thereby supporting integrated farming systems. In industrial contexts, macrophytes such as *Eichhornia crassipes* and *Pistia stratiotes* are employed in effluent treatment ponds to remove heavy metals and reduce pollutant loads before discharge or further treatment. Additionally, urban lake restoration projects in cities like Bengaluru have adopted floating treatment wetlands, where macrophytes help in controlling eutrophication, improving dissolved oxygen levels, and restoring ecological balance. These applications demonstrate that macrophytes can function effectively as low-cost, nature-based solutions across multiple sectors, making them highly adaptable to Indian environmental and socio-economic conditions.

Conclusion

Macrophytes offer a sustainable and cost-

effective solution for water remediation in India. Their adaptability, efficiency in pollutant removal, and suitability for decentralized systems make them highly valuable. Integrating macrophyte-based approaches can significantly improve water quality while supporting ecological restoration and resource recovery in diverse environmental settings.



Sustainable Cucumber Farming

S. A. Maqdoom Sha, Priya Prabhakar Satwadhar and Devshree Dhanraj Panchbhai

Abstract

The primary objective of this article is to highlight the economic importance of cucumber cultivation and promote the adoption of sustainable agricultural practices. It emphasizes reducing excessive use of synthetic chemicals through the integrated use of biofertilizers, organic inputs, and limited chemical fertilizers. This balanced approach helps maintain soil health while ensuring stable yield and profitability.

Origin and Climate Requirements

Cucumber is believed to have originated in the Indian subcontinent and has been cultivated for over 3,000 years. It thrives best under warm and humid climatic conditions, which promote rapid vegetative growth and fruit development. The ideal temperature range for cucumber cultivation is between 18°C and 35°C. Temperatures below this range, especially frost or chilling conditions, can damage the crop by inhibiting growth and causing flower drop. On the other hand, excessively high temperatures may reduce pollination efficiency and fruit quality. Therefore, maintaining an optimal temperature range is essential for achieving higher productivity

Soil and Land Preparation: Cucumber grows well in well-drained sandy loam to loamy soils rich in

organic matter. The ideal soil pH ranges from 6.0 to 7.5. Proper land preparation involves deep ploughing to loosen the soil, followed by the incorporation of well-decomposed farmyard manure to improve fertility and soil structure. Raised bed formation (15-30 cm height) is recommended to ensure proper drainage and root development. The use of drip irrigation and plastic mulching further enhances soil moisture conservation, reduces weed growth, and improves crop performance.



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Transplanting and Crop Establishment: Healthy and disease-free seedlings are essential for successful crop establishment. Before transplanting, seedlings should be treated with beneficial bioagents such as *Trichoderma* and *Pseudomonas* to prevent soil-borne diseases. Maintaining proper spacing (about 60 cm between plants) ensures adequate aeration and sunlight penetration. It is also important to maintain the “vapsa condition,” which refers to optimal soil moisture with sufficient aeration, to support root growth and plant establishment.

Integrated Nutrient Management: Integrated Nutrient Management (INM) plays a vital role in improving crop yield and soil health. Cucumber requires balanced application of primary nutrients such as nitrogen (N), phosphorus (P), and potassium (K), along with secondary and micronutrients. Nitrogen promotes vegetative growth, phosphorus supports root development, and potassium enhances fruit quality. The use of biofertilizers like *Azotobacter* and phosphate-solubilizing bacteria improves nutrient availability and reduces dependency on chemical fertilizers. Fertilizer application should ideally be based on soil testing to avoid excess use and reduce input costs.

Efficient nutrient management is essential for growth and productivity

Schedule

Day 1: Transplanting Day 3-4: NPK (2 g litre⁻¹) Seaweed extract (Biovita/Isabion) Micronutrients (Melange) *Trichoderma* + Rootmax Day 12: Phosphoric acid (85%) Urea (2 g litre⁻¹) MOP (2 g

litre⁻¹) Combi + *Pseudomonas* Day 25: NPK + Sulphur.

Flowering Stage: Yaramila Complex + Urea + Biovita + NPK Apply 5 kg acre⁻¹ (adjust for early/late flowering) Biofertilizers Recommended *Trichoderma*, *Pseudomonas*, PSB (Phosphate Solubilizing Bacteria) and *Azotobacter*.

Water Management: Cucumber has a shallow root system and requires frequent irrigation for optimal growth. Drip irrigation is considered the most efficient method as it provides water directly to the root zone, minimizes water wastage, and maintains uniform soil moisture. Maintaining the vapsa condition is crucial to avoid both waterlogging and drought stress. Excess water can lead to root diseases, while insufficient water can reduce fruit yield and quality.

Pest Management: Cucumber is susceptible to several insect pests such as aphids, thrips, beetles, and fruit flies. These pests damage the plant by sucking sap or feeding on leaves and fruits, leading to reduced growth and yield. Integrated Pest Management (IPM) strategies, including the use of neem-based products, biological control agents, and sticky traps, are effective in controlling pest populations. Chemical control should be used only when necessary and in a judicious manner to minimize environmental impact.

Common Pests and Control Measures Thrips: Neem oil, Azadirachtin, *Beauveria bassiana*, or Thiamethoxam.

Red Pumpkin Beetle: Neem oil or Malathion

Epilachna Beetle: Biological control (BVM)

Leaf Miner: Eamectin benzoate + BVM

Aphids: Sticky traps, Imidacloprid, Thiamethoxam

Fruit Fly: Methyl eugenol traps, Spinosad

Disease Management: Common diseases affecting cucumber include downy mildew and powdery mildew, which are mainly caused by fungal pathogens. These diseases can reduce photosynthesis and significantly impact yield. Preventive measures such as proper spacing, good air circulation, and field sanitation are essential. The use of biological fungicides and need-based chemical treatments can effectively manage disease outbreaks.

Downy Mildew: Trichoderma, Mancozeb, Azoxystrobin

Powdery Mildew: *Bacillus subtilis*, Karathane Gold Myclobutanil

Staking and Training: Staking or training cucumber plants using bamboo or other supports helps improve plant growth and fruit quality. It allows better sunlight exposure, reduces disease incidence, and makes harvesting easier. Proper training also enhances air circulation within the crop canopy, thereby reducing the risk of fungal infections.

Varieties: Several high-yielding hybrid varieties of cucumber are cultivated in India, differing in fruit size, color, shape, and resistance to pests and diseases. Farmers generally prefer varieties that produce dark green, uniform fruits with good shelf life and high market demand. Selection of suitable varieties depends on local climate conditions,

season, and market requirements. In India, commonly cultivated varieties include Malini, NS 404, Pusa Uday, Pusa Barkha, Swarna Ageti, and Poona Khira, which are well adapted to open field conditions and provide stable yields under different agro-climatic regions. For southern states such as Andhra Pradesh and Telangana, hybrids like Malini and other locally adapted varieties perform well due to their tolerance to heat and consistent fruiting. For protected cultivation and export markets, parthenocarpic (seedless) hybrids are highly preferred due to their uniform shape, attractive appearance, and better shelf life. Popular export-quality varieties include Kian, Multistar, Hilton, and other greenhouse hybrids, which produce long, straight, dark green fruits suitable for international markets. These varieties are mainly grown under polyhouse or greenhouse conditions to meet export standards. Thus, choosing the right variety based on cultivation method (open field or protected), market demand, and climatic suitability plays a crucial role in maximizing yield and profitability. Recommended varieties South India (Telangana / Andhra / Karnataka) Malini, (high yielding hybrid) Poinsett (disease resistant), Kian (parthenocarpic hybrid) North India (UP, Punjab, Haryana, Bihar). Pusa Uday, Pusa Barkha, Swarna Ageti, Poona, Khira Nazia, Sumitra, Shiny, Shivalik.

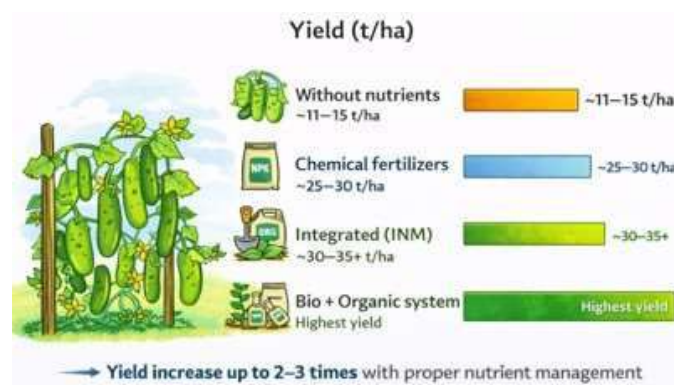
Cost of Cultivation: The cost of cucumber cultivation includes expenses on land preparation, seedlings, fertilizers, irrigation systems, mulching, and labor. Among these, mulching and drip irrigation

account for a major portion of the total cost but significantly improve yield and water-use efficiency. Proper cost management and efficient resource utilization are essential for maximizing profitability.



Profitability and Economic Importance: Cucumber is a short-duration crop with high yield potential, making it economically attractive for farmers. With proper management practices such as drip irrigation, mulching, and integrated nutrient and pest management, higher productivity and better market prices can be achieved. Profitability mainly depends on efficient production practices, proper timing of harvest, and effective cost management. Under good cultivation practices, the average yield of cucumber can reach approximately 22 to 25 tonnes acre⁻¹. The income from this yield varies depending on market price fluctuations. For instance, if the market price is around ₹20 kg⁻¹, farmers can earn approximately ₹4,40,000 to ₹5,00,000 acre⁻¹. When the price increases to ₹30 kg⁻¹, the income may rise to about ₹6,60,000 to ₹7,50,000 acre⁻¹. In favorable market conditions, if the price reaches ₹40 kg⁻¹, the total income can go up to ₹8,80,000 to ₹10,00,000 acre⁻¹. Cucumber cultivation is also highly recommended for agriculture students and beginners who want to

take their first step into farming, as it is a short-duration crop with quick returns and relatively easier management compared to long-duration crops.



Marketing Strategies (Including Online Marketing): Marketing is one of the most critical factors in determining profit. Farmers can sell cucumbers through local markets, wholesale mandis, supermarkets and direct farm sales. Timing plays a key role selling during high-demand periods, especially summer, ensures better prices. In addition to traditional methods, online marketing is becoming increasingly important. Farmers can sell produce through: Online agricultural marketplaces Social media platforms (WhatsApp, Facebook groups) Direct-to-consumer delivery models Online marketing helps farmers reach more customers, reduce dependency on middlemen, and obtain better prices. Proper grading, packaging, and maintaining quality are essential for both offline and online sales.

Conclusion

The primary objective of this article is to promote sustainable agriculture and support farmers through practical knowledge. Based on personal experience and an agricultural background, it highlights the importance of balanced nutrient mana-

gement using biofertilizers, organic inputs, and limited chemical use. Cucumber cultivation is recommended as an ideal starting point for both agriculture and non-agriculture students, as it offers easy management, valuable field experience, and good profit potential. Overall, this article encourages taking initial steps toward sustainable and profitable farming.



Opportunity Crop in Rainfed Agriculture: Boosting Farmers Income and Climate Resilience in India

Kamali M. H., A. P. Srividhya and J. Paul Mansingh

Introduction

Indian agriculture system is completely based on rainfall where nearly 56% of total cultivated land is under rainfed agriculture around 40% of farmers population depends on rainfall. On the other side there are crops that are climate resilience and have high potential to improve food security and farmers income these crops are called as opportunity crops. But they are not widely cultivated compared to other major crops like rice, maize etc even though these opportunity crops adapt well to local environmental conditions such as limited rainfall, poor soil conditions and extreme climates. The objective is to understand the potential of these opportunity crops in improving rainfed agricultural condition in India which can further enhance farmers income, build climate resilience and support sustainable agriculture by improving food security

Rainfed Indian Agriculture: Economic and Climate Challenges

In many parts of India, rainfed agriculture acts as a backbone. Even after achieving full irrigation half of the India's cultivated area still depend on rainfall for irrigation. Farmers cultivate crop mainly based on season but the variable rainfall pattern which majorly affect the productivity of

small and marginal farmers. Due to irregular and frequent change in the climate and rainfall there may be a huge production risk due to crop failure and low yield. As a result, compared to Irrigated agriculture rainfed farming is highly associated with production risk More than 60 percent of country's net sown area are rainfed and 42% of the area cultivated by major grains such as pulses, cereals and oilseeds which contribute to total grain production. According to the data given by Directorate of economics and statistics around 43.6% of India's net sown area does not have irrigation which means farmers only depend on rain. Some states such as Manipur, Sikkim, Assam and Maharashtra have very high level of rainfed farming due to limited irrigation facility. Climate change has been the critical component for yield loss in rainfed farming system increasing temperature and changing rainfall pattern made weather unpredictable to measure leading to increase changes in livelihood and reduce the stability of agricultural production followed by major problems such as irregular irrigation and drought condition, soil degradation and declining soil fertility which further reduce the productive capacity of agricultural land. As a result, the income of farmers becomes uncertain and the food security in rural area may be affected.

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To address all these challenges, we require an innovative and resilient agricultural approach

Concept and Characteristics of Opportunity Crops

As we all know major crop which dominate the global diet are rice, wheat, maize but there are few crops including millets, pulses, leafy vegetables, oilseed, roots, tubers and pseudocereals which are rich in essential nutrients like iron, calcium, zinc and vitamins. Those crop with provide adequate nutrient and environment benefits which are traditional, indigenous or locally adapted but are often under-utilized is termed as opportunity crops. Opportunity crops, also known as Neglected and Underutilized species (NUS), offer benefits to diversify food systems with nutritious and climate-resilient foods (Fig. 1).



Fig. 1: Characteristics of opportunity crops

Role of opportunity crop in food security

Many opportunity crops are considered to be nutritive, improving food security, especially grow in rainfed and drought prone region. Most of these crops have shorter growing period which allow

farmer to harvest quickly and ensure continuous food supply for increasing population. Recently various international organization have highlighted the importance of opportunity crop in sustainable agriculture by actively promoting it. Food and Agriculture Organization (FAO), have been creating awareness about these opportunity crop through the international treaty on plant genetic resources for food and agriculture. During 2024, World Food Forum (WFF), initiatives such as exhibition and youth programme highlighted how opportunity crop can support climate resilient agriculture and food security. They also help address hidden hunger and seasonal nutritional gap. For example, both dietary diversity and soil fertility can be improved by pulses such as chick pea, lentils, cow pea and Horsegram which are rich in protein and can fix nitrogen. For example, 100 kcal of Amaranthus leaves can provide over 100% of daily calcium and iron level which more important requirement for women's of reproductive age.

Benefits to Farmers: Opportunity crops are very useful to farmers, especially in rainfed and dryland agriculture where farming is highly risky since they are depending only on the rainfall as a source of irrigation. These crops can grow well under less water and poor soil conditions. At the same time, they provide stable yield under difficult and extreme climatic conditions. These crops also provide an additional income opportunities through different uses such as food, feed, fodder and value addition (example: Moringa). They also act as a backup crop

when grown along with the major crops which can be cultivated or relied upon when the main crop fails due to drought or unfavourable conditions. Overall, it can improve their income, reduce risk and practical sustainably healthy agricultural practices. The benefits of opportunity crops are illustrated in Fig. 2.



Fig. 2. Benefits of opportunity crop in various sector

Barriers to Adaptation: Despite these opportunity crops having several benefits, barriers for adaptation are comparatively higher (Fig. 3). One major limitation in incorporating these crops in farming systems is the lack of improved varieties, which impedes farmers from accessing quality planting materials of these crops compared to other major crops. Even though the Minimum Support price (MSP) exist for various opportunity crops, just as a principal farmer cultivating these crops mostly relay on local market price which are comparatively lower. The MSP in India highly support and concentrate on major cereals such as rice, wheat etc as government buys most of these in larger quantity for public distribution and also provide larger Food Corporation of India (FCI) warehouses for storage due to the presence of higher cultivated land area. Extension services related to these crops were quite limited

compared to other major crops especially farmers in rainfed areas lack in awareness, training guidance related to production and benefits of growing these crops. Current policies do not sufficiently support them, promotion for these crops were less effective and less impactful. Few of these opportunity crops are highly susceptible to pest and diseases and also require various labour intensive procedures according to the crop type and variety. Preference and lifestyle of people in present modern era have also changed which eventually affect the demand of these crops and market value. Together these barriers affect the large scale adaptation of these opportunity crops.



Fig. 3: Barriers for adaptation

Conclusion

Being in a country highly depending on rainfed which forms the backbone of Indian farming system, farmers face various challenges such as low and erratic rainfall, low soil fertility, lack of irrigation, and vulnerability to climate change. In this situation opportunity crop plays a significant role in providing practical solutions by producing high value produce which are potential for multiple use such as food, feed, medicinal and industrial most importantly the also contribute for climate resilience as they are drought and heat tolerant, can grow under low fertility conditions and can also improve soil health when intercropped with other main crop. Despite, there advantages there few barriers for ada-

ptation such as lack of awareness, labour intensive cultivation practices, limited access to improved seed and low consumer demand. These challenges and limitations can be addressed through various policies and institutional support. Global conservation initiatives by Crop Trust and community based biodiversity programs by the M.S Swaminathan Research Foundation (MSSRF) help in conserving genetic resources of various indigenous crops, provide farmers with improved variety, standardize agronomic practices etc. They also facilitate market linkages which can eventually promote the wider adaptation of opportunity crops. Overall, integration of opportunity crop into rainfed agriculture not only enhance food and nutritional security but also strengthens and support farmers livelihood, ensures sustainable resource use and also build resilience against climate variability which has been a major issue

References

- Suresh, A., S. S, Raju, Chauhan, S. and K. R. Chaudhary (2014). Rainfed agriculture in India: An analysis of performance and implication. Indian Agriculture Research Inside, New Delhi 110012
- Welthungerhilfe. (2024). Opportunity crop for better nutritional - capability statement- capability-statement-opportunity-crops-welthungerhilfe .pdf
- Harriss-White, B (2008). Introduction: India's rainfed agricultural dystopia. *The European Journal of Development Research*, 20(4).
- Pravin, T. Raj. (2024) Millet's cultivation in India: Challenges and Opportunity towards achieving sustainable farming and inclusive development. *Madras Agricultural Journal*, MAJ-2024_1758097532.pdf
- Singh, V. K. and Prabhakar, M. (2025). Challenges and opportunities in rainfed agriculture. ICAR- central research institute for Dryland Agriculture, Hyderabad icar.pdf
- Karl, Kevin. (2024). Opportunity crop indicator: Assessing the climate adaptation potential of opportunity crop in Africa Opportunity _Crop_Indicators_Assessing_the_Climate_.pdf
- Rachel C. Voss, de Sousa, N' Danikou. (2025). Citizen science informs demand driven breeding of opportunity crops plants people planet-2025-voss-citizen science inform demand driven.pdf
- Next IAS. (2024). Food security in India: challenges and opportunity <https://www.nextias.com/blog/food-security/>
- FAO. (2025). International Treaty Highlights Opportunity crop. Food and Agriculture Organization of the United Nation <https://www.fao.org/plant-treaty/news/news-detail/International-Treaty-Highlights-Opportunity-Crops/>
- Crop Trust. (2025). Opportunity crop Knowledge Base <https://www.croptrust.org/knowledge-hub/opportunity-crops/about/>

Quorum Sensing in Bacteria: A Mechanism of Cell-to-Cell Communication

Vishal D. Pawar and Kishor T. Thakre

Introduction

Quorum Sensing is a mechanism of cell-to-cell communication in bacteria, in which they use small chemical signaling molecules called autoinducers to interact with each other. This process enables bacteria to sense their population density and regulate their behavior collectively. Earlier, bacteria were considered as independent unicellular organisms, but it is now known that they can function as a coordinated group. In quorum sensing, individual bacterial cells continuously release autoinducers into the environment. At low cell density, the concentration of these molecules remains too low to be detected. However, as the bacterial population increases, the concentration of autoinducers rises and reaches a critical threshold level. Once this threshold is achieved, the signaling molecules bind to specific receptors and activate the expression of certain genes. As a result, bacteria exhibit coordinated activities such as biofilm formation, production of virulence factors, and adaptation to environmental changes. Quorum sensing is particularly important in plant pathology, as many plant pathogenic bacteria use this mechanism to regulate infection processes and enhance disease development.

What is Quorum Sensing?

Quorum Sensing refers to the ability of bacteria to communicate with each other through small signaling molecules called autoinducers and regulate gene expression based on population density. The term “quorum” means the minimum number of individuals required to perform a particular activity. Similarly, in bacteria, a certain population density is required to trigger a coordinated response. In this process, bacteria produce and release autoinducers into their surroundings. At low population density, the concentration of these molecules remains low and no significant response occurs. As the population increases, the concentration of autoinducers also increases. When it reaches a threshold level, these molecules bind to specific receptors and activate or repress target genes. This leads to coordinated group behavior such as biofilm formation, production of virulence factors, and other physiological activities.

General Mechanism of Quorum Sensing

In Quorum Sensing, two main components are essential:

- ✓ Autoinducers (signaling molecules)
- ✓ Receptors (signal detecting proteins)

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A brief overview of the process

Bacterial genes code for the production of signaling molecules called autoinducers that are released into the bacterium's surrounding environment.



These signaling molecules then bind to signaling receptors either on the bacterial surface or in the cytoplasm.



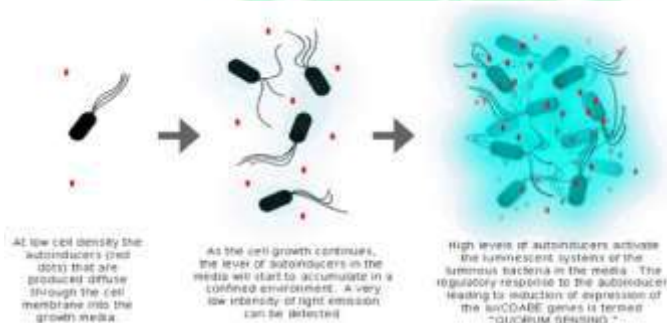
When these autoinducers reach a critical threshold level, they activate bacterial quorum sensing genes that enable the bacteria to behave as a multicellular population rather than as individual single-celled organisms.



The autoinducer/receptor complex is able to bind to DNA promoters and activate the transcription of quorum sensing-controlled genes in the bacterium.



In this way, individual bacteria within a group are able to benefit from the activity of the entire group.



When the inducer binds the receptor, it activates transcription of certain genes, including those for inducer synthesis.

QS depends on three basic principles

- ✓ The members of the community produce AIs which are signalling molecules.

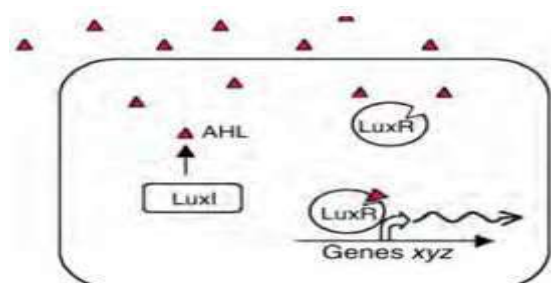
- ✓ AIs are detected by receptors that exist in the cytoplasm or in the membrane.
- ✓ In addition to activating expression of gene necessary for cooperative behaviour, detection of AIs results in activation of AI production.

Quorum Sensing In Gram-Negative & Gram-Positive Bacteria

Mechanism in Gram-Negative Bacteria: In Gram-negative bacteria, quorum sensing is mainly mediated by Quorum Sensing using Acyl Homoserine Lactones (AHLs) as signaling molecules.

Stepwise Mechanism

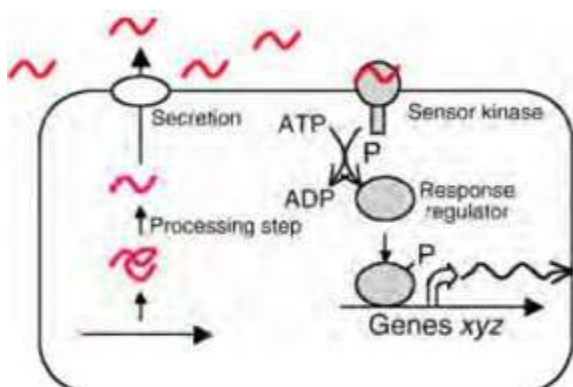
- ✓ The autoinducers in Gram-negative bacteria are AHL (Acyl Homoserine Lactones).
- ✓ AHL molecules are synthesized inside the bacterial cell by a LuxI homolog.
- ✓ These AHL molecules freely diffuse in and out of the bacterial cell membrane.
- ✓ As bacterial population increases, AHL concentration also increases in the environment.
- ✓ At a critical threshold level, AHL binds to the cytoplasmic receptor protein LuxR homolog.
- ✓ The AHL-LuxR complex acts as a transcriptional activator.
- ✓ This complex binds to DNA and activates expression of specific genes responsible for group behavior.



Mechanism in Gram-Positive Bacteria: In Gram-positive bacteria, quorum sensing works through Quorum Sensing using small peptide-based signaling molecules.

Stepwise Mechanism

- ✓ The autoinducers in Gram-positive bacteria are oligopeptides (small peptide molecules).
- ✓ These peptide signals are synthesized inside the cell.
- ✓ They are secreted outside the cell through ABC (ATP-Binding Cassette) transporters.
- ✓ As bacterial population increases, peptide concentration in the environment increases.
- ✓ When a threshold level is reached, peptides bind to a membrane-bound receptor called histidine kinase.
- ✓ This activates a phosphorylation cascade inside the cell.
- ✓ The signal is transferred to response regulator proteins, which activate gene transcription.
- ✓ This leads to coordinated behaviors such as biofilm formation, virulence, and competence development.



Quorum Quenching (Inhibition of Quorum Sensing): Quorum Sensing can be inhibited by a

process called quorum quenching, which blocks bacterial communication. In this process, the signaling system of bacteria is disrupted by:

- ✓ Degradation of autoinducers
- ✓ Blocking receptor binding
- ✓ Inhibiting signal production

This prevents bacteria from coordinating their activities.

Examples

- ✓ Enzyme AiiA breaks AHL molecules
- ✓ *Bacillus thuringiensis* produces quorum quenching enzymes
- ✓ Marine algae produce compounds that interfere with signaling

Importance of Quorum Sensing

- ✓ It helps bacteria to behave as a coordinated group
- ✓ Regulates virulence factor production during infection
- ✓ Essential for biofilm formation, which protects bacteria from antibiotics and environment
- ✓ Helps bacteria survive in changing environmental conditions
- ✓ In plant pathogens, it increases disease severity and spread

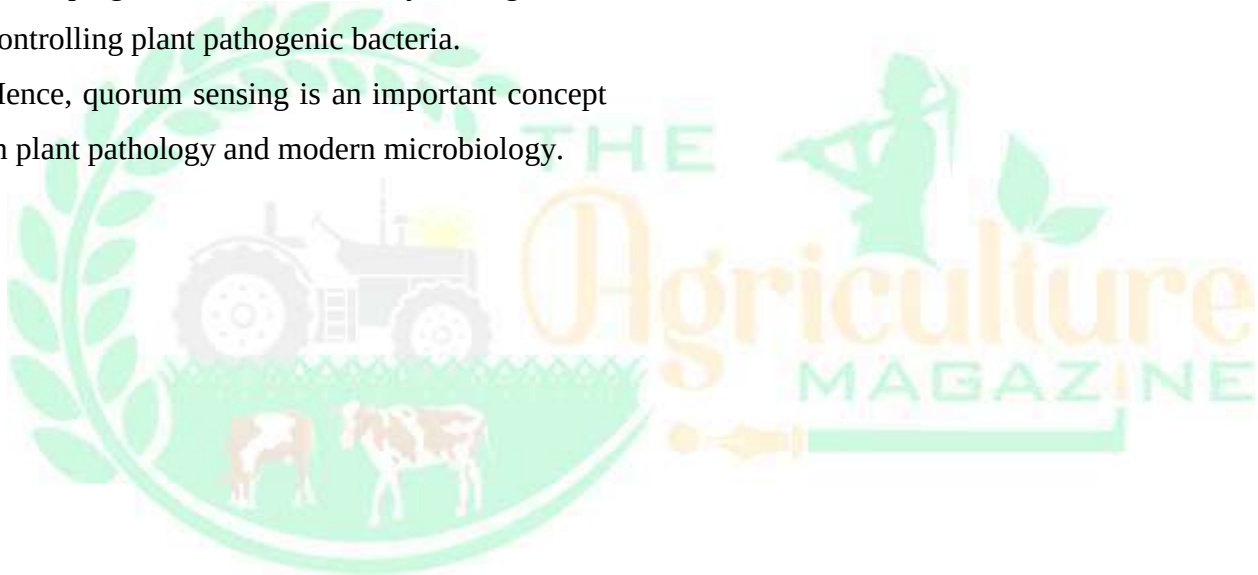
Applications in Plant Pathology

- ✓ Used in development of disease-resistant crop varieties
- ✓ Helps in biological control of plant pathogens
- ✓ Targeting bacterial communication instead of killing bacteria
- ✓ Prevention of diseases like soft rot, blight, and wilt

- ✓ Development of eco-friendly and sustainable agriculture practices

Conclusions

- ✓ Quorum Sensing is a sophisticated communication system in bacteria that allows them to coordinate gene expression based on population density.
- ✓ It plays a crucial role in bacterial virulence, biofilm formation and plant disease development. Understanding this mechanism helps in developing new and eco-friendly strategies for controlling plant pathogenic bacteria.
- ✓ Hence, quorum sensing is an important concept in plant pathology and modern microbiology.



Bridging Farmers and Urban Consumers: Direct Organic Product Distribution by My Harvest Farms

Pravin Kumar Amirthalingam, Indhra Prakash S. G., Srinidhi Prasad and J. Paul Mansingh

Introduction

Agriculture plays a vital role in ensuring food security and supporting rural livelihoods in India. In recent years agricultural startups use modern technologies and the digital platforms to improve the efficiency of agricultural supply chains and provide a better market opportunities for farmers. My Harvest Farms, located in Chennai, operates using this farm-to consumer approach. My Harvest Farms sources organic and naturally grown agricultural products directly from the farmers and delivers them to customers through an organised logistics system. This article presents the operational structure of My Harvest Farms and the learning experiences gained by our team during the internship period.

About My Harvest Farms

My Harvest Farms is an agricultural startup based in Chennai that focuses on delivering fresh organic and naturally grown products directly to the consumers. The company operates on a farm-to-consumer business model that connects farmers with urban households while reducing the number of intermediaries in the supply chain. They source vegetables, fruits, greens and grocery products from farmers who practice organic farming methods. After sourcing the products from farmers, they handle sorting, packaging and delivery operations to ensure

that consumers receive fresh and high-quality produce. This model ensures product freshness, improving the transparency in sourcing and helps farmers to receive fair prices for their produces. Customers place the orders through digital platforms such as mobile applications or online ordering systems. They also emphasize hygiene and quality during the packaging process. Proper labelling and sealing of products are carried out to maintain safety and traceability. Delivery routes are planned using digital route optimization tools to ensure efficient distribution, Products are then delivered directly to consumers homes, helping maintain freshness and customer satisfaction. Through this system, My Harvest Farms supports farmers by providing better market access while also offering consumers healthy and chemical-free food products.



Fig. 1: Farm to consumer supply chain model adopted by My Harvest Farms

Internship Activities and Observations

During the internship period, our team had the opportunity to observe and participate in several operational activities carried out by the organization.

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Customer success operation: Customer satisfaction is an important aspect of direct-to-consumer businesses. Our team assisted in organising customer feed back data, feedback forms were digitalized to collect structured information regarding product quality services and consumer experience.

Data Management: We also assisted in organising product and consumer data to support operational planning, records related to product availability, inventory levels and sales were maintained to ensure proper stock management.

Content developing and digital marketing: Our team participated in designing product visuals and promotional materials using Canva, these materials were used on digital platforms to present products effectively and attract customers.

Delivery planning and Routing: The company used route optimization tools to plan delivery schedules. During the internship, we used RouteXL software to identify efficient delivery routes.

Inventory and Packaging: We also learned in sorting vegetables according to quality standards before packaging. Products were packed and labelled properly to maintain hygiene and quality.

Learning Outcomes

This internship provided us with valuable insights into agribusiness operations and startup based agricultural supply chains. We gained a clear understanding of how the farm-to-consumer supply chain model functions in real-world-situations, observing the sourcing, packaging and delivery processes helped us to understand how this model

improves the efficiency in agricultural marketing. We also had an exposure to logistics management and delivery coordination, which are important for handling perishable agricultural products. We gained practical exposure in inventory management, packaging practices and quality control of fresh produce. The use of digital tools for marketing, route planning and customer feedback management also demonstrated the growing role of technology in agribusiness operations. In addition to technical knowledge, this internship improved our teamwork, communication and time management skills.

Conclusion

My Harvest Farms demonstrates the increasing role of agricultural startups in improving traditional food supply chain; by implementing a farm-to-consumer distribution model, this company reduces the involvement of intermediaries and ensures that consumers receive fresh and high-quality agricultural products. This internship provides our team with practical exposure to several aspects of agribusiness operations including inventory management, packaging, logistics coordination and customer engagement.

Acknowledgement

We sincerely thank MyHarvest Farms for providing us with the opportunity to complete our internship and gain practical exposure in agribusiness operations and farm-to-consumer supply chain management. We express our gratitude to the management and staff members of My Harvest Farms for their guidance and support during the

internship period. Their practical explanations helped us to understand how agricultural startups operates and how fresh agricultural products are distributed directly to consumers.

Reference

https://myharvestfarms.com/?srsltid=AfmBOoopYu eIxZRdY_IQY4x7YCJ77wjLRcxzO1wRKpKn8U5_oh3NxeX2



Organic Spinach Cultivation for Safe Food Production

M. Kabilan, T. Anitha and V. Balamurugan

Introduction

Spinach (*Spinacia oleracea* L.) is a highly nutritious leafy vegetable widely consumed across the world due to its rich content of vitamins, minerals, antioxidants and dietary fiber. It is particularly valued for its high levels of iron, calcium, vitamin A, vitamin C and folates, making it an essential component of a balanced diet. However, conventional spinach production often involves the excessive use of chemical fertilizers and pesticides, which can lead to the accumulation of harmful residues, posing risks to human health and the environment. In this context, organic spinach cultivation has gained significant importance as a sustainable and eco-friendly approach to produce safe and nutritious food. Organic farming relies on natural inputs, ecological processes and biodiversity to maintain soil fertility, control pests and diseases and enhance crop productivity. Organic spinach cultivation not only ensures food safety but also improves soil health, reduces environmental pollution and promotes sustainable agriculture.

Principles of Organic Spinach Cultivation:

Organic spinach cultivation is based on principles such as maintaining soil fertility through organic

inputs, enhancing biodiversity, avoiding synthetic chemicals and promoting ecological balance. The use of compost, farmyard manure, green manures and biofertilizers forms the foundation of nutrient management in organic systems. Crop rotation, intercropping and the use of cover crops help improve soil structure and reduce pest and disease incidence. Organic certification standards ensure that produce is free from synthetic chemicals and meets safety and quality requirements.



Agro-Climatic Requirements and Soil Conditions

: Spinach is a cool-season crop that thrives under moderate climatic conditions, with an optimum temperature range of 15°C to 25°C. It grows well in well-drained, fertile soils rich in organic matter, with a pH range of 6.0 to 7.5. Soil fertility is particularly important in organic systems, as nutrient availability depends on microbial activity and organic matter decomposition. Proper soil preparation, including the incorporation of organic manures, ensures a favorab-

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le environment for root growth and nutrient uptake.

Selection of Suitable Varieties: The selection of suitable spinach varieties is crucial for organic cultivation. Varieties that are fast-growing, high-yielding and resistant to pests and diseases are preferred. Local and indigenous varieties often perform better under organic conditions due to their adaptability and resilience. Improved varieties such as Pusa Palak, All Green and Jobner Green are commonly grown in organic systems due to their high productivity and quality.

Seed Treatment and Sowing: In organic farming, seed treatment is carried out using biological agents and natural substances to protect against seed-borne diseases. Treatments with *Trichoderma* spp., *Pseudomonas fluorescens*, or plant extracts such as neem help enhance germination and seedling vigor. Seeds are sown directly in the field at appropriate spacing to ensure optimal plant population. Proper spacing improves air circulation, reduces disease incidence and promotes uniform growth.

Organic Nutrient Management: Nutrient management in organic spinach cultivation relies on natural sources such as farmyard manure, compost, vermicompost and green manures. These inputs improve soil structure, enhance microbial activity and provide a slow and steady supply of nutrients. Biofertilizers such as *Azospirillum* and phosphate-solubilizing bacteria help improve nutrient availability and uptake. Foliar application of organic liquid fertilizers such as panchagavya and seaweed extracts can enhance growth and yield. Balanced

nutrient management is essential to achieve high productivity and maintain soil health.

Water Management: Efficient water management is essential for organic spinach cultivation, as the crop requires consistent soil moisture for rapid growth and tender leaf production. Drip irrigation is an effective method that ensures uniform water distribution, reduces water wastage and minimizes disease incidence. Mulching with organic materials such as straw or leaves helps conserve soil moisture, regulate temperature and suppress weeds.



Weed Management: Weed management in organic systems is achieved through cultural and mechanical methods. Manual weeding, mulching and the use of cover crops help suppress weed growth. Maintaining a weed-free environment during the early stages of crop growth is crucial for achieving higher yields.

Organic Pest and Disease Management: Organic pest and disease management relies on preventive and biological control methods. The use of neem-based products, botanical extracts and biopesticides helps control pests such as aphids and leaf miners. Beneficial insects such as ladybird beetles and parasitoids play an important role in controlling pest populations. Crop rotation and proper sanitation reduce disease incidence. Biological control agents such as *Trichoderma* spp. and *Bacillus subtilis* are effective in managing soil-borne diseases.

Harvesting and Yield: Spinach is a short-duration crop and can be harvested within 25-40 days after sowing. Harvesting is done by cutting the leaves or uprooting the entire plant, depending on market demand. Multiple harvests can be obtained by cutting outer leaves, allowing the plant to regrow. Organic spinach yields are generally slightly lower than conventional yields; however, the premium price for organic produce compensates for this difference.

Post-Harvest Handling and Food Safety: Post-harvest handling is critical in maintaining the quality and safety of organic spinach. Leaves should be handled carefully to avoid contamination and mechanical damage. Washing with clean water and proper packaging help maintain freshness and reduce microbial contamination. Organic certification ensures that the produce meets safety standards and is free from harmful residues.

Environmental and Health Benefits: Organic spinach cultivation offers numerous environmental and health benefits. It reduces the use of synthetic chemicals, thereby minimizing soil and water pollution. Organic farming practices enhance soil fertility, biodiversity and ecological balance. Consumption of organic spinach reduces exposure to pesticide residues and contributes to better health.

Constraints and Challenges: Despite its advantages, organic spinach cultivation faces challenges such as lower initial yields, higher labor requirements and limited availability of organic inputs. Pest and disease management can be more

challenging in the absence of chemical pesticides. Certification processes and market access also pose constraints for small farmers.

Future Prospects

The future of organic spinach cultivation is promising due to increasing consumer demand for safe and healthy food. Advances in organic farming technologies, improved varieties and better market linkages will enhance adoption. Integration of organic farming with precision agriculture and digital tools can further improve productivity and sustainability.

Conclusion

Organic spinach cultivation is a sustainable approach to producing safe and nutritious food while preserving environmental health. By adopting organic practices such as natural nutrient management, biological pest control and efficient water management, farmers can achieve good yields and high-quality produce. The growing demand for organic vegetables presents significant opportunities for farmers to enhance income and contribute to sustainable agriculture. Continued research, policy support and farmer awareness are essential to promote organic spinach cultivation on a larger scale.

References

- Lampkin, N. (2002). *Organic Farming*. Old Pond Publishing.
- Worthington, V. (2001). Nutritional quality of organic versus conventional crops. *Journal of Alternative and Complementary Medicine*, 7(2): 161-173.

- Pimentel, D., Hepperly, P., Hanson, J., Douds, D. and Seidel, R. (2005). Environmental, energetic and economic comparisons of organic and conventional farming systems. *BioScience*, 55(7): 573-582.
- Meena, R. S., Kumar, S. and Meena, V. S. (2019). Nutrient management in vegetable crops. *Agricultural Reviews*, 40(3): 181-188.



Boosting Flower-to-Pod Success in Legumes: Smart Strategies for Higher Yields

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Abstract

Legumes are vital for food security, soil health, and sustainable agriculture. Although India is the largest producer and consumer of pulses, productivity remains low due to agronomic, genetic, and physiological constraints. Delayed sowing, poor nutrient and water management, pest pressure, indeterminate growth, and high flower drop reduce yield. Low flower-to-pod conversion is a major limitation. Integrated nutrient management, foliar feeding, plant growth regulators, proper irrigation, and pest control can improve pod set and yield stability. Combining improved management practices with stress-tolerant varieties is essential to bridge the demand-supply gap.

Introduction

Legumes, fitting to family Fabaceae or Leguminosae, are the edible seeds of leguminous plants. It has roughly 670-750 taxa and 18,000-19,000 species. The term “food legumes” refers to a group of common legumes, including the chickpea or bengal gram (*Cicer aritenum*), mung bean or green gram (*Vigna radiata*), soybean (*Glycine max*), peanut (*Arachis hypogea*), lentil (*Lens culinaris*), cowpea (*Vigna unguiculata*), moth bean (*Vigna aconitifolia*), pea (*Pisum sativum*) and faba bean (*Vicia faba*). Food legumes are divided into two groups: pulses and oilseeds. In contrast to pulses, which are dry seeds eaten as food, oilseed legumes

are legumes with significantly high oil content. India is the largest producer and consumer of food legumes in the world. Worldwide, the total production of pulses is reported to be 89.8 million tonnes from an estimated area of 93.1 million hectares with average productivity of 963.9 kg ha⁻¹. In India, it is grown across 33.1 million hectares with an annual production of 23.36 million tonnes and an average yield of 704.2 kg ha⁻¹.

Importance of Legumes: Legumes improve soil fertility by fixing atmospheric nitrogen and reducing the need for chemical fertilizers. They grow well even under adverse environmental conditions and require less water than many cereal crops. They are

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environmentally friendly crops, producing lower greenhouse gas emissions and helping in carbon sequestration. Legumes also support the livelihoods of smallholder farmers by providing food and income. Nutritionally, they are rich in protein and fibre and help in maintaining good health by reducing the risk of diabetes, heart disease, and high cholesterol.

Gap between Supply and Demand: India is the largest producer and consumer of pulses in the world. Despite this, India imported pulses worth more than 119 billion Indian rupees in the financial year 2021. Per capita consumption of pulses was about 67 g per person per day in 1951, which declined to 35 g in 2010, and later increased to 45 g in 2021. To achieve self-sufficiency by 2050, India needs to produce around 50 million tonnes of pulses, which requires an annual growth rate of about 4.2%. However, pulse crops are often given lower priority compared to cereal crops in terms of cultivation and policy support.

Constraints in Pulse Production

Agonomic Constraints: Pulse crops often suffer due to improper sowing time, which exposes them to stress and pest attack, reducing yield. Low seed rate and poor plant population lead to inadequate crop stand. Broadcasting instead of line sowing makes intercultural operations difficult. Because of their slow initial growth, pulses face severe weed competition during the early stages. Lack of irrigation during flowering and pod development reduces pod setting. Poor nutrient management and limited use of quality

Rhizobium culture restrict nitrogen fixation. In addition, high incidence of pests and diseases causes yield instability.

Genetical Constraints: Many pulse varieties have low reproductive efficiency due to high flower drop and poor pod retention. Non-synchronous flowering and indeterminate growth habit create uneven maturity and harvesting problems. Limited resistance to pests and diseases increases crop vulnerability. Some varieties show unstable performance across environments. Low seed replacement rate and lack of stress-tolerant varieties further limit productivity.

Physiological Constraints: Pulse crops generally have a low harvest index, producing more vegetative growth than grain yield. Weak source-sink relationships and high flower shedding reduce pod filling. Sensitivity to day length and temperature affects flowering and pod development. Long crop duration and limited response to fertilizers also reduce overall productivity.

Measures to Improve Flower to Pod Ratio in Legumes

Nutrient Management: Balanced and timely nutrient supply supports proper reproductive growth in pulses. Starter nitrogen helps early growth until nodulation begins, while phosphorus promotes root development and flowering. Potassium reduces stress-induced flower drop, and sulphur supports amino acid and seed formation. Micronutrients like boron improve fertilization, and molybdenum enhances nitrogen fixation. Soil test-based and integrated

nutrient management ensures better pod setting (Rajput *et al.*, 2022).

Foliar Nutrition: During flowering, nutrient demand is high and root uptake may be limited. Foliar sprays such as 2% DAP or 1% NPK provide quick nutrient supply. Boron improves pollen growth, and potassium enhances stress tolerance. Foliar feeding maintains chlorophyll and strengthens source-sink relations, improving pod retention (Masih *et al.*, 2020).

Plant Growth Regulators (PGRs): Flower drop is often linked to stress-induced ethylene production. Application of NAA (20-40 ppm) at flowering reduces abscission and improves flower retention. Proper use of PGRs enhances assimilate movement toward pods and increases pod set without excessive vegetative growth (Patil *et al.*, 2023).

Pulse Wonder / Pulse Magic: Pulse Wonder is a balanced foliar nutrient mixture with macro- and micronutrients plus growth promoters. It improves chlorophyll content, photosynthesis, stress tolerance, and pod filling. Compared to DAP spray, it provides more balanced nutrition and improves yield stability (Vinodhini *et al.*, 2022).

Nipping and Growth Regulation: Nipping reduces apical dominance and increases branching, leading to more flowering nodes. Improved canopy structure enhances light use and pod formation. Growth retardants help divert assimilates toward reproductive parts and improve flower-to-pod conversion (Jaidka *et al.*, 2018).

Irrigation Management: Moisture stress during

flowering reduces fertilization and increases flower drop. Irrigation at flower initiation and pod development ensures better nutrient flow and pod set. Avoiding waterlogging is equally important for maintaining root health (Giri *et al.*, 2011).

Pest and Disease Management: Insects like pod borers, thrips, and aphids damage flowers and pods, reducing yield. Timely pest management and regular monitoring protect reproductive parts and improve pod formation (Meena *et al.*, 2020).

Conclusion

Pulse productivity is limited mainly by poor reproductive efficiency and management constraints. Improving flower retention through balanced nutrition, moisture management, and pest protection, along with adoption of high-yielding, stress-tolerant varieties, is crucial for achieving sustainable pulse self-sufficiency.

References

- Patil, P. M., Thombre, P. R., Thombre, A. B., Deosarkar, D. B. and Gore, V. B. (2023). Effect of spraying NAA on soybean (*Glycine max* (L.) Merrill.) var. MAUS 71 growth, yield, and seed quality. *Journal of Pharma Innovation*, 12(12): 1037-1045.
- Jaidka, M., Deol, J. S. and Brar, A. S. (2018). Development of optimized source-sink relationship, favourable morpho-physiological behaviour and profitability of soybean through detopping and mepiquat chloride application. *Journal of Crop and Weed*, 14 (1): 82-89.

- Giri, U., Kundu, P., Chakraborty, A. and Bandyopadhyay, P. (2011). Effect of sulphur and different irrigation regimes on groundnut. *Journal of Crop and Weed*, 7(2): 80-83.
- Masih, A., Dawson, J. and Singh, R. E. (2020). Effect of levels of phosphorus and zinc on growth and yield of greengram (*Vigna radiata* L.). *Current Journal of Microbiology and Applied Science*, 9(10): 3106- 3112.
- Meena, S. N., Patidar, B. K., Jadon, C., Meena, H. P., Meena, B. S., Yadav, R. K., Yadav, S. L., Meena, N. L., Singh, P. and Jat, M. L. (2020). Response of pigeonpea [*Cajanus cajan* (L.)] to foliar application of nutrient and pest management at flowering stage. *International Journal of Bio-resources and Stress Management*, 11(5): 432-436.
- Rajput, S., Shukla, N., Rajendralakpale, R. G. and Saxena, R. R. (2022). Studies on the effect of culture, liquid and capsulated bio fertilizer on yield attributes of vegetable pea (*Pisum Sativum* L.) cv. Kashi Nandini. *Journal of Pharma Innovation*, 11(6): 1206-1212.
- Vinodhini, P., Albert Arokiasamy, A. and Selvamuthukumaran, S. (2022). Effect of foliar application of nutrients on the yield enhancement of green gram (*Vigna radiata* L.). *Journal of The Pharma Innovation*, 11 (12): 761-762.

Yoghurt: A Functional Fermented Dairy Product

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Abstract

Yoghurt is a fermented dairy product produced through the bacterial fermentation of milk, primarily by *Lactobacillus delbrueckii* subsp. *bulgaricus* and *Streptococcus thermophilus*. It is widely consumed across cultures due to its appealing taste, digestibility, and health-promoting properties. Yoghurt is rich in high-quality protein, essential vitamins, minerals such as calcium and phosphorus, and probiotics, which collectively contribute to improved gut health, enhanced immunity, and reduced risk of chronic diseases. Beyond its basic nutritional value, yoghurt functions as a “functional food,” supporting digestive comfort, bone health, metabolic balance, and immune function. The consumption of yoghurt has been linked to beneficial effects on weight management, cardiovascular health, and glycemic control.

Introduction

Yoghurt has been consumed for thousands of years, with origins traced to Central Asia and the Middle East. It is believed that nomadic herders first discovered yoghurt when milk fermented naturally in animal-skin containers. Today, yoghurt is produced industrially under controlled conditions using specific bacterial starter cultures. It is one of the oldest and most globally consumed fermented dairy foods, appreciated not only for its sensory qualities but also for its nutritional and functional benefits. The lactic acid-driven fermentation of milk by *Lactobacillus delbrueckii* subsp. *bulgaricus* and *Streptococcus thermophilus* transforms lactose into lactic acid, creating yoghurt’s characteristic texture, tangy taste, and enhanced digestibility compared with unfermented milk products (Sumi *et al.*, 2023). Yoghurt is evolving as a “functional food” a food

that delivers health benefits beyond basic nutrition, particularly when enriched with probiotic cultures. Li *et al.* (2025) emphasize that probiotic yoghurt formulations not only improve the sensory and nutritional profile of the product but also enhance physiological functions such as gut microbiota regulation and immune modulation. Jena and Choudhury (2025) underscore that probiotic and prebiotic components in fermented dairy products like yoghurt can contribute to improved gastrointestinal homeostasis and may aid digestion and nutrient absorption through their interaction with the intestinal ecosystem. Yoghurt is not solely a nutrient-dense dairy product but also a dynamic functional food with potential contributions to digestive health, metabolic regulation, immune function, and overall nutritional quality.

Nutritional Value of Yoghurt

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Yoghurt is a nutrient-dense dairy product whose composition varies depending on the type of milk used (whole, low-fat, or skim) and the methods of processing. It provides a rich source of macronutrients, essential vitamins and minerals, and beneficial probiotics, making it a valuable component of a balanced diet.

Macronutrients

Protein: Yoghurt contains high-quality protein with all essential amino acids, supporting tissue growth, repair, and overall metabolic functions.

Carbohydrates: The primary carbohydrate is lactose, which is partially broken down during fermentation, making yoghurt more digestible, especially for individuals with mild lactose intolerance.

Fats: The fat content varies with the type of milk used, contributing to energy supply and fat-soluble vitamins.

Micronutrients

Calcium and Phosphorus: Essential for maintaining bone and teeth health, calcium and phosphorus work together to strengthen skeletal structure.

Vitamin B₁₂: Crucial for red blood cell formation and neurological function.

Riboflavin (Vitamin B₂): Supports energy metabolism and overall cellular function.

Potassium: Helps regulate blood pressure and maintains electrolyte balance.

Probiotics

Yoghurt contains live beneficial micro-

organisms, including strains of *Lactobacillus* and *Bifidobacterium*, which promote a healthy gut microbiota. These probiotics aid digestion, enhance nutrient absorption, and support immune function, contributing to overall wellness.

Health Benefits of Yoghurt

Improves Digestive Health: The probiotics in yoghurt enhance gut flora balance, reduce symptoms of lactose intolerance, and may prevent diarrhea associated with antibiotic use.

Supports Bone Health: Yoghurt is an excellent source of calcium and phosphorus, essential for maintaining bone density and reducing the risk of osteoporosis.

Boosts Immune Function: Probiotic bacteria stimulate the immune system by enhancing the activity of natural killer cells and increasing antibody production.

Promotes Heart Health: Regular yoghurt consumption has been associated with lower blood pressure and reduced risk of cardiovascular disease, partly due to its potassium and bioactive peptides.

Aids in Weight Management: High-protein yoghurt increases satiety, helping control appetite and reduce overall calorie intake.

Reduces Risk of Type 2 Diabetes: Some epidemiological studies suggest that regular yoghurt intake may lower the risk of developing type 2 diabetes.

Conclusion

Yoghurt is a highly nutritious and versatile fermented dairy product that provides numerous

health benefits. Its rich nutrient profile, including high-quality protein, vitamins, and minerals, combined with the presence of beneficial probiotic microorganisms, makes it an important component of a balanced diet. The fermentation process not only enhances digestibility and nutrient availability but also supports gut health and overall well-being. Regular consumption of yoghurt can contribute to digestive comfort, strengthen bones, boost immune function, and promote overall health. By bridging traditional dietary practices with modern nutritional science, yoghurt remains a valuable food for maintaining a healthy and balanced lifestyle.

References

- Sumi, K., Tagawa, R., Yamazaki, K., Nakayama, K., Ichimura, T., Sanbongi, C. and Nakazato, K. (2023). Nutritional value of yogurt as a protein source: digestibility/absorbability and effects on skeletal muscle. *Nutrients*, 15(20): 4366.
- Li, B., Ye, L., Zhao, Y., Wang, M. and Zhang, Q. (2025). A comprehensive review of probiotic yogurt: Nutritional modulation, flavor improvement, health benefits, and advances in processing techniques. *Agricultural Products Processing and Storage*, 1(17).
- Jena, R. and Choudhury, P. K. (2025). Unveiling probiotic and prebiotic functional dairy foods: A health beneficial outlook. *3Biotech*, 15(6): 175.

Chickpea (*Cicer arietinum* L., Mexican type) Intercropped with Sunflower (MSFH-17) under Drip Irrigation: Effects on Pest Incidence, Disease Reduction, Soil Fertility and System Productivity

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Abstract

A field demonstration was conducted on 4 acres during the *rabi* season to evaluate the performance of Mexican chickpea intercropped with sunflower hybrid MSFH-17 under drip irrigation. The cropping system followed a 4:1 row ratio (Chickpea: Sunflower). Seed rate was maintained at 25 kg acre⁻¹ for chickpea and 1 kg acre⁻¹ for sunflower. The study assessed pest incidence, disease severity, soil fertility improvement, water use efficiency, and system productivity. Intercropping reduced *Helicoverpa armigera* infestation by 28-36% and Fusarium wilt incidence by 15-22% compared to conventional monocropping. Biological nitrogen fixation improved soil nitrogen status by approximately 50-60 kg N ha⁻¹. Drip irrigation enhanced water use efficiency by 30-40%. The Land Equivalent Ratio (LER) exceeded 1.25, confirming system advantage. The chickpea-sunflower intercropping model proved agronomically efficient, pest-resilient, and environmentally sustainable.

Introduction

Chickpea (*Cicer arietinum* L.) is an important pulse crop contributing to nutritional security and soil fertility through biological nitrogen fixation. Mexican (Kabuli) chickpea types fetch premium market prices but are highly susceptible to insect pests such as *Helicoverpa armigera* and diseases including Fusarium wilt and dry root rot.

Intercropping of legumes with oilseeds is a sustainable intensification strategy that enhances biodiversity, suppresses pests, improves nutrient cycling, and increases land productivity. Sunflower hybrid MSFH-17 (Mahyco) is a high-yielding hybrid suitable for drip irrigation and semi-arid regions.

The present study aimed to scientifically evaluate chickpea-sunflower intercropping under drip irrigation with special emphasis on pest suppression, disease management, soil fertility improvement, and system productivity.

Materials and Methods

Crop Details

Parameter	Chickpea (Mexican)	Sunflower (MSFH-17)
Seed rate	25 kg acre ⁻¹	1 kg acre ⁻¹
Spacing	30 × 10 cm	60 × 30 cm
Row ratio	4	1

Experimental Site

Total area: 4 acres

Season: *Rabi*

Soil type: Medium black soil

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Irrigation method: Drip irrigation

Nutrient Management

Chickpea: 25:50:0 kg NPK ha⁻¹

Sunflower: 60:60:40 kg NPK ha⁻¹

Fertigation applied through drip system

Pest and Disease Management

Seed Treatment

- ✓ *Trichoderma viride* @ 4 g kg⁻¹ seed
- ✓ Carbendazim @ 2 g kg⁻¹ seed

Major Insect Pest Management

Pest	Chemical	Dose
Pod borer (<i>H. armigera</i>)	Emamectin benzoate 5 SG	0.4 g L ⁻¹
Aphids	Thiamethoxam 25 WG	0.25 g L ⁻¹
Capitulum borer	Spinosad 45 SC	0.3 ml L ⁻¹

Disease Management

Fusarium wilt: Seed treatment + crop rotation

Dry root rot: *Trichoderma* soil application @ 2.5 kg acre⁻¹

Alternaria blight (sunflower): Mancozeb 75 WP @ 2 g L⁻¹

Observations Recorded

- ✓ Pest incidence (%)
- ✓ Disease incidence (%)
- ✓ Soil available nitrogen (kg ha⁻¹)
- ✓ Yield (q ha⁻¹)
- ✓ Land Equivalent Ratio (LER)

Results and Discussion

Pest Suppression: Intercropping significantly reduced pod borer incidence (28-36%) due to:

- ✓ Trap crop effect of sunflower
- ✓ Enhanced natural enemy population
- ✓ Disruption of pest host-finding behavior

The diversified canopy reduced aphid multiplication and improved biological control efficiency.

Disease Reduction: Fusarium wilt incidence was reduced by 15-22% compared to sole chickpea. The diversified cropping system and drip irrigation reduced soil moisture fluctuations and pathogen build-up.



Soil Fertility Improvement: Chickpea contributed approximately 50-60 kg N ha⁻¹ through biological nitrogen fixation. Increased root biomass enhanced soil organic carbon and microbial activity.

Water Use Efficiency: Drip irrigation reduced water use by 30-40%, minimized weed growth, and improved nutrient uptake efficiency.

System Productivity: The Land Equivalent Ratio (LER) exceeded 1.25, indicating intercropping advantage. The system improved economic returns and reduced production risk.

Conclusion

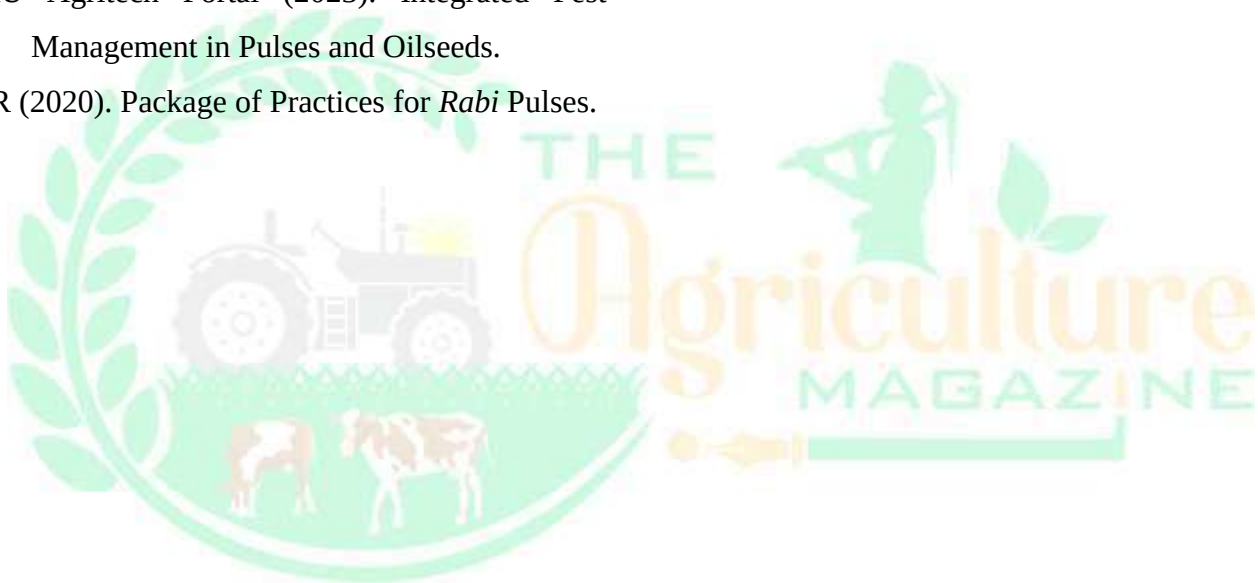
Mexican chickpea intercropped with sunflower MSFH-17 under drip irrigation demonstrated superior pest suppression, disease reduction, soil fertility enhancement, and water productivity. The system is sustainable, economically viable, and suitable for semi-arid agro-ecosystems.

Acknowledgement

The authors acknowledge the support of farmers and institutional guidance during the field demonstration.

References

- Ali, M. and Kumar, S. (2009). Chickpea research in India: Accomplishments and future strategies. *Indian Journal of Agricultural Sciences*.
- ICAR-IIPR (2022). Chickpea Production Technology Manual.
- ICAR-IIOR (2021). Sunflower Production Guide.
- TNAU Agritech Portal (2023). Integrated Pest Management in Pulses and Oilseeds.
- ICAR (2020). Package of Practices for *Rabi* Pulses.



Sustainable Livestock Farming

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Livestock farming is a cornerstone of agriculture globally, providing essential food products, livelihoods and increasing opportunities for innovation. However, it is increasingly recognized that modern livestock farming practices often involving mass production and intense resource use contribute to climate change environmental degradation. However, alternatives exist, and plenty research indicates that a combination of improved livestock feed and integrated livestock farming methods could reduce the impact of livestock farming and even offer important ecosystem benefits such as the improvement of soil fertility.

Sustainable livestock farming

In contrast to today's conventional methods of livestock farming, sustainable livestock farming integrates environmental, social and economic factors into animal production systems, thus minimizing negative impacts on ecosystems, conserving natural resources and increasing animal welfare. Sustainable livestock farming often revolves around the following methods that reduce pollution, conser-

ve water and minimize the use of chemical agriculture inputs. The various beneficial aspects of livestock farming are development of global agricultural economy, rural livelihood up-gradation, rural women's empowerment and sustainable rangeland management, conservation of domestic animals and enhancing soil fertility and nutrient cycling. As per the report of FAO, the grazing land is more than the cropping land. The grazing land covers about 60% of the total agriculture land, and support 360 million cattle and 600 million sheep and goats. About 10% of the world's beef meat and 30% sheep and goat meat are produced from grazing animals worldwide. In addition, sustainable livestock farming not only save the land for cropping but also helpful in maintaining nitrogen and phosphorus balance. The goat's excreta are rich in nitrogen and phosphorus. By adapting biogas production techniques from ruminant farm organic wastes, methane gas can be produced to meet the energy demand of farm house, and the slurry leftover after biogas production can be used as bio-fertilizer for foliage feedstock production for animals.

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In a sustainable livestock farming system one can monitor the feed conversion efficiency (FCE). It is a biological process to calculate the number of products in terms of milk, meat and other derivatives produced per unit of feed supply to an animal. The efficiency can be increased by application of new technologies in converting feed energy to milk or meat energy. The individual consumes feed as source of energy; the source of energy is converted into different products such as meat, milk, and fibre in livestock. The energy gained by an individual is used for body maintenance such as digestion, metabolism, growth and immune function. After fulfilling the body requirement, the energy is channelized for milk or fibre production.

Benefits of Sustainable Livestock Farming

Environmental Conservation: Sustainable practices help reduce negative environmental impacts of livestock farming such as deforestation, soil erosion and water pollution. This contributes to the preservation of ecosystems and biodiversity.

Lower greenhouse gas emissions: Sustainable livestock farming aims to reduce methane emissions from animals, a potent greenhouse gas. Implementing practices like improving feeding and waste management can help mitigate climate change.

Improved Animal welfare: Sustainable farming includes ethical treatment of animals providing those proper living conditions and humane handling that leads to better animal welfare.

Enhanced Resource efficiency: Sustainable practices optimize the use of resources like water and feed,

reducing waste and inefficiencies in livestock production.

Healthier food products: Sustainable farming can lead to safer and higher quality animal derived products, as animals are healthier and less reliant on antibiotics and other chemicals.

Economic Resilience: Sustainable livestock farming can enhance the resilience of farming communities by diversifying income sources.

Social Benefits: Sustainable practices can improve livelihoods in rural communities, promote equitable access to resources and strengthen the social fabric of farming communities.

Consumer demand: Growing consumer awareness of sustainability issues has led to the demand for sustainably produced animal products, providing marketing opportunities for farmers.

Sustainable livestock farming involves a range of practices that aim to balance the need for food production with environmental stewardship, animal welfare, and social responsibility. Here are some specific practices commonly associated with sustainable livestock farming:

Rotational Grazing: This practice involves rotating livestock between different pastures to promote healthy grass growth and reduce overgrazing.

Benefits: Improves soil health, enhances biodiversity, reduces land degradation and increases carbon sequestration.

Integrated Crop: Livestock Systems: Combining crop production with livestock rearing to optimize land use and resource efficiency.

Benefits: Manure from livestock serves as fertilizers for crops, and crop residues can feed animals, reducing waste and dependency on synthetic fertilizers.

Agroecology: A holistic approach that considers the entire ecosystem, emphasizing biodiversity, soil health, and sustainable practices.

Benefits: Enhances resilience to climate change, reduces reliance on chemical inputs, and promotes ecosystem services.

Improving Feed Efficiency: Using techniques such as precision feeding, which tailors feed based on the nutritional needs of animals to minimize waste.

Benefits: Reduces feed costs, lessens methane emissions from ruminants, and lowers the overall environmental footprint of meat and dairy production.

Animal Welfare Practices: Ensuring that animals have adequate space, proper nutrition, and access to outdoor areas to promote their well-being.

Benefits: Improves the health and productivity of livestock, reduces stress, and enhances product quality.

Manure Management: Implementing systems for recycling manure as a resource rather than a waste product, including composting or anaerobic digestion.

Benefits: Reduces greenhouse gas emissions, prevents nutrient runoff into water bodies, and provides organic fertilizer for crops.

Breeding for Resilience: Selecting and breeding livestock that are more resilient to diseases, climate

variability, and environmental stresses.

Benefits: Improves herd health, productivity, and adaptability to changing environmental conditions.

Diverse Livestock Species: Integrating a variety of animal species in farming systems to enhance biodiversity and ecological stability.

Benefits: Reduces pest and disease pressures, provides a range of products, and promotes resilience against market fluctuations.

Community Engagement and Education: Involving local communities and stakeholders in decision-making processes and providing educational resources on sustainable practices.

Benefits: Fosters collaboration, increases awareness about sustainable practices, and supports the social dimensions of sustainability. These practices can be adapted based on local conditions, available resources, and specific farming goals. Successful sustainable livestock farming requires an integrated approach that considers environmental, economic, and social factor.

Challenges associated with sustainable livestock farming

Limited resources such as land and water:

Livestock farming requires large amounts of land for grazing and growing animal feed crops. Water is a critical resource for livestock, and its excessive use can lead to water scarcity in certain regions.

The high costs of fertilizers and animal feed: High costs of fertilizers and animal feed are a major problem for livestock farmers in several nations. Rising costs of these crucial inputs can make it more

difficult for farmers to run viable businesses, especially for small-scale producers.

Preference for imported agricultural products:

The prioritization of lower-priced imported agricultural products can discourage local farmers and hinder their economic viability. This preference for imports often stems from consumers seeking lower prices, which may not account for the sustainability or quality of locally produced goods.

Rise of alternative dairy and meat products:

Alternative dairy and meat products that don't depend on conventional livestock production are becoming more popular. A growing number of people are choosing plant-based foods because they are ethical and environmentally friendly, such as almond milk and plant-based burgers. This shift in consumer preferences poses a direct threat to the traditional livestock business, pushing it to adapt to changing consumer needs.

Animal welfare concerns: Ethical concerns about how animals are handled in industrial agricultural operations have prompted discussions about the livestock sector's social aspects. These concerns also include issues related to working conditions and rural livelihoods.

Increasing global demand for animal protein: The global demand for animal protein continues to rise, presenting a challenge in meeting food security needs sustainably. Finding ways to produce adequate protein sources while minimizing the environmental footprint of livestock farming is a significant challenge.

Conclusion

Sustainable livestock farming stands as a beacon of hope for our planet's future. By adhering to the principles of responsible resource management, ethical animal care, and innovative technologies, we can address the pressing challenges of climate change, resource scarcity, and the growing demand for protein. As we navigate the path toward sustainability in livestock farming, we must remain vigilant in our efforts to protect the environment, promote animal welfare, and support the livelihoods of those who depend on this industry. The adoption of regenerative practices, the harnessing of new technologies and the willingness to adapt to changing consumer preferences are all integral to this journey. In the face of global challenges, sustainable livestock farming offers a promising path forward—a path that balances the needs of the present with the well-being of future generations and the health of our planet. It is a path worth treading, for it leads us toward a more sustainable, ethical, and harmonious coexistence with the natural world.

The Best Management Strategies for Applying Biochar in Crop Fields

Mrinal Choudhury, Diksha Hazarika, Jwngsar Moshahary and Britan Rahman

Introduction

Biochar is a product resulting from biomass pyrolysis. Biochar usage has increased because it reduces the negative impacts of bio mass burning on the environment. The physicochemical properties of biochar are what govern the applications of this material. Depending on the feedstock type, production technology and process conditions the quality of the resulting biochar differs. It has got a wide range of applications that range from adsorption for water and air pollutants, activated carbon, anaerobic digestion promoter/catalyst, construction material, agriculture and horticulture use such as soil conditioning, compost additive, carbon sequestration etc. These applications of biochar contribute to the circular economy through its uses in agriculture and horticulture. Also, these numerous biochar benefits show a great potential to contribute to the economic sustainability of emerging cellulosic bioenergy production systems. Biochar application in agriculture and horticulture has been explored in the field. These applications include being used as a component of chemical fertilizer, soil microbial activity, soil amendment for crop productivity improvement through nutrient availability as well as water holding capacity. Biochar has also been reported to alleviate heavy metals release in the soil while having a limiting effect that aids in increasing

the pH of highly acidic soils. Though biochar is another soil conditioner type, it differs from compost by production pathways. Biochar is produced by thermal decomposition of food, horticultural and municipal solid waste in the absence of oxygen, while natural biodegradation of organic substrates produces compost by the microbial community under aerobic conditions. Another difference is that; compost degrades fast; making its benefits relatively short lived compared to biochar which persists in the soil for more prolonged periods. Biochar has been applied to remediate contaminated agricultural soil and improve soil fertility by reducing acidity and increasing the availability of nutrients. Thus, the addition of biochar to soils can be one of the best practices to overcome any biotic stress in soil and increase crop productivity, mainly in the agricultural sector. As far as soil application is concerned, biochar can be considered as a sustainable soil amendment that serves one or more of the following:

- ✓ Builds soil organic carbon and soil health
- ✓ Increases crop yields and soil moisture
- ✓ Improves nutrient retention
- ✓ Boosts microbial activity
- ✓ Alleviates compaction
- ✓ Reduces soil acidity
- ✓ Sequesters carbon

Like any other external input used in the

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agricultural fields, the interacting factors affecting the efficacy of biochar are

- ✓ Soil
- ✓ Crop
- ✓ Environment
- ✓ Management practices

The 4Rs of biochar applications in agricultural fields

Biochar application to soils requires a similar strategy as the 4Rs of nutrient stewardship: right source, right place, right rate, and right timing. When biochar is used appropriately it can help farmers achieve maximum crop productivity and improve soil health, while minimizing environmental impacts. Using the 4Rs improves the efficacy of soil biochar applications.

Right source: Selecting the best biochar for the crop is of utmost importance. The best source of material for making biochar is local, available and would otherwise be a waste product. Depending on where a farm is located some feedstocks to produce biochar include poultry litter, manure, rice hulls, corn stover, vine/tree prunings, coconut husks, woodchips, straw, sugarcane bagasse, etc. Biochar is also produced from biosolids, construction waste and other materials that may pose a contamination risk when applied to soils. To select the ideal biochar, knowledge of the original feedstock is important. If possible, the biochar needs to be analyzed prior to its use. Sometimes the best biochar may be far away, making it very expensive. Biochar quality and availability are important factors to consider while

deciding to use it. Farmers should consult with an agricultural professional or their local agricultural officer for help selecting and applying biochar. The best applications occur when the right biochar is applied at the right rate to address a particular issue. Feedstock and pyrolysis conditions influence the resulting biochar's physical and chemical properties. the issue or limiting factors that biochar might help address include soil compaction, water retention, nutrient use efficiency (NUE), soil organic matter levels, and pH. Other objectives could be to sequester carbon or generally improve soil health.

Right place: It is very important to ensure that biochar is applied to the soils that need it. Not all soils and crops will see a yield benefit from biochar applications, making it essential to know which soils will likely generate a positive crop yield response. Soil maps can help identify soils that would potentially benefit the most from biochar applications. In horticultural applications, biochar can replace non renewable potting materials including peat, vermiculite and perlite. Biochar can also be a key component in many different conservation practices or management strategies. For example, biochar can improve the soil condition and assist with vegetation establishment and plant growth in the field border or grassed waterway.

Right rate: The farmers should make sure to apply the right amount of biochar based on the deficiency in the soil and requirement of the crop. There is no one-size-fits-all answer regarding the amount of biochar to be applied. Application rates are site-specific and

should be determined to correct or improve a production constraint or resource concern. Soils vary in their deficiencies and needs, and application rates are determined on a field-by-field basis to address a specific issue. Field application rates of between 1-10 tons acre⁻¹ have shown consistent positive impacts in numerous studies. A good starting point for field applications is 1 ton/acre as the lowest effective rate to improve soil organism habitat and 3 ton acre⁻¹ to improve soil organic matter levels. For container production or tree planting holes, 5-25% by volume maintains good plant performance. Economics are often a factor. Higher rates of the ideal biochar are usually better, but they typically are not cost effective.

Right time: For obtaining the desired effect one should to when to apply biochar into the soil. Biochar can be applied at any time of year except when the ground is frozen. Pre-monsoon months application is the most common time to apply biochar. But often, a better time to apply biochar is after harvest and with a cover crop. This provides time for the biochar to equilibrate in the soil. However, it would be imperative to have a cover crop in this situation to prevent runoff and utilize excess nutrients from the biochar amendment. Applying biochar with other amendments or during other management operations may save farmers time and money and reduce the risk of erosion loss. Most common examples are mixing and spreading biochar with manure, chicken litter or compost.

Importance of post-processing (charging/

inoculating/ blending)

Biochar, a relatively inert material, serves as the backbone or carrier of nutrients and shelter for microorganisms. Inoculating, charging, activating, blending or mixing essentially fills biochar surface functional groups with nutrients and microbes to initiate surface reactions. When applied to the soil, inoculating biochar is critical to minimize the potential for nutrient immobilization (tying up of nutrients), which can lead to a yield drag or loss, particularly in the first year of application. Filling the pore spaces in biochar with nutrients, fertilizers or microbially active substrates minimizes a potential yield loss and improves the efficacy and potential for positive impacts from biochar. Mixing biochar with manure, compost or other amendments may also improve the efficiency of those amendments. Many different sources can be used to inoculate biochar - compost, manure, compost tea, fertilizer, urine, microbial inoculants. Selecting one depends on availability, scale and farmers' fertility practices. The time needed to activate before use varies; 1-3 weeks has been recommended.

The benefits of charging biochars led to the development of biochar-based fertilizers (BBFs) that take advantage of the opportunity to produce biochars tailored for specific needs and use different pre- or post-pyrolysis methods to load biochar with nutrients.¹³ Farmers can speak directly with biochar suppliers to create customized biochar blends to meet their fertility needs or purchase formulated BBFs directly from fertilizer companies.

Single Vs. Repeated Applications

Because biochar resists decomposition in soil, single applications can provide beneficial effects over many growing seasons. Thus, biochar does not usually need to be applied annually, like manures, compost, synthetic fertilizers, and other amendments. Yet repeated or incremental applications can be made with current management practices (e.g., fertilizer or compost applications). Considering economics, logistics or mechanization in no-till systems, smaller amounts of biochar can be applied on a more frequent basis. One tradeoff is that changes to soil properties may take longer to be realized. In perennial cropping systems (e.g. vineyards, orchards and ornamentals), applying biochar at the time of planting directly into the planting row ensures incorporation into the soil profile and within the root zone. For existing plantings repeated surface applications can be made in-row or between rows, though it is best to mix with compost or fertilizer to reduce risk of loss.

In pasture or range systems, applying biochar before grazing can be advantageous to incorporation, but forage height and livestock type play a role in that decision. The best time to apply biochar in pasture settings is right after livestock have rotated through a paddock, so biochar is combined with residual manure and urine.

Application Equipments and Methods

Common farm equipments can be used to apply biochar including compost/manure spreaders, lime spreaders, broadcast seeders, tillage implemen-

ts, seed drills and liquid injection. Which piece of equipment is used will depend on the cropping system, biochar particle size, size of the farm and other management practices.

Broadcast applications and incorporation:

Biochar can be broadcasted to the soil surface by hand (small scale) or using a lime, manure, or compost spreader (larger scale). Biochar is ideally applied in combination with other amendments, as discussed above, to reduce risk of wind erosion. Incorporate the biochar into the soil when possible using available tillage implements to minimize any further losses.

Liquid injection, fertigation and top dressing: For farms where liquid manure injection is common (dairy and field crops), micronized biochar (0.02 mm particle size) can be incorporated into the liquid slurry before application to fields or initially added to manure lagoons to provide a variety of benefits. Micronized biochars can be suspended in water and injected into the root zone of perennial crops or fertigated, which could provide a slow but steady method of adding biochar to the root zone via irrigation water. The micronized biochar suspended in water can also be used to top-dress turf grass, fields, golf courses and lawns. This also helps decrease the likelihood of losses due to wind or water erosion.

Trenching in perennial crops: Targeting biochar to the planting row or planting hole where the roots will have access to the nutrients is ideal. Also, adding biochar to the planting hole is more economical than

applying it to the entire row.

Drilling/banding in pastures and no-till fields:

Biochar can be mixed with seed and/or fertilizer in no-till drills and banded into the soil with minimal disturbance to the soil surface. Ensure the biochar is dry (<20% moisture) before mixing to prevent caking in the drill.

Other considerations

Pelletized biochar is produced by compacting residual biochar into small pellets with or without a binder. Pelletizing biochar with chicken litter, hay or another appropriate binder makes application easier with existing equipment. The denser pellets minimize potential loss when biochar is top-dressed. The type of binder varies, but using a urea ammonium sulfate is a good option to supply additional N and balance the C:N ratio.

Prilled biochar: A product like prilled urea with biochar can offer the most compatible substrate for farmers to use in existing fertilizer application equipment. Over 20 studies revealed a 15-69% delay in N release and 25-65% improvement in fertilizer use efficiency with prilled biochar-based N fertilizer.

Incorporate biochar into the soil, when possible, using tillage implements, which is often the most practical method of application. Moistening biochar can further reduce losses due to wind at the time of application. However, biochar that is too wet may be difficult to spread depending on equipment used. Mixing with manure or compost aids in spreadability. Biochar by itself is very dry and dusty, so appropriate personal protective equipment (e.g.,

dust mask, goggles, and gloves) may be required. It is best to apply biochar during calm weather conditions.

Conclusion

Biochar can enhance the physical and chemical characteristics of soil, enhancing its fertility and productivity. Further, adding biochar to soils is beneficial for lowering methane and nitrous oxide emissions, nutrient leaching into groundwater, and soil contaminant levels, among others. The benefits from biochar applications to the agricultural land include augmented capacity to hold onto water and nutrients in the surface soil strata for extended periods of time because it prevents nutrients from evaporating from the crop root zone, potentially increases crop yields, and lowers the need for fertilizer. Improved soil quality, a decrease in nitrate load in soil and groundwater, a rise in humification, the ability to retain nutrients and water, and tolerance to drought conditions are further advantages of applying biochar to soil. In future the biochar should be utilized as soil amendment (broadcasting, traditional banding, mixed in soil, mixed with liquid fertilizers and target application in precision farming) for improving the soil health and combating the burgeoning climate market. Therefore selection of the materials and methods pertaining to biochar application is of utmost importance for reaping the desirable benefits.

Concept and Differentiation of Intercropping and Mixed Cropping; Criteria in Assessing the Yield Advantages

Alka, Sumit Chaudhary, Madhulika Pandey and Taniya

Introduction

Cropping systems refer to the pattern and sequence in which crops are grown on a given piece of land over time. Since the beginning of agriculture farmers have developed different cropping systems to maximize land productivity ensure food security and reduce the risk of crop failure. Early farming practices were largely based on monocropping, where a single crop was grown repeatedly on the same land. However, continuous monocropping led to problems such as nutrient depletion, pest buildup, and declining yields. To overcome these limitations, more diversified cropping systems evolved including multiple cropping, intercropping, mixed cropping, and crop rotation. These systems aim to make better use of natural resources like soil, water, sunlight, and nutrients while maintaining soil fertility and ecological balance. Modern cropping systems also focus on sustainability, economic returns, and environmental protection by reducing dependence on external inputs and improving resilience to climate variability. As a result, cropping systems play a vital

role in sustainable agriculture by enhancing productivity, stabilizing yields, and promoting efficient resource use. Multiple cropping systems play an important role in sustainable agriculture by improving the efficient use of natural resources such as land, water, light, and nutrients. By growing more than one crop on the same field within a year or at the same time, these systems help increase total productivity per unit area and time. Multiple cropping also reduces the risk of complete crop failure, as different crops respond differently to pests, diseases, and climatic stress. It contributes to better soil health through improved organic matter content, enhanced nutrient cycling and reduced soil erosion. In addition, multiple cropping systems support biodiversity and reduce dependence on chemical fertilizers and pesticides, making farming more environmentally sustainable and economically stable for farmers.

Intercropping and mixed cropping are important components of multiple cropping systems because they help maximize yield and stabilize farm income. Intercropping allows the systematic arrange-

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ment of two or more crops so that they complement each other in the use of resources, leading to higher combined yields compared to sole cropping. Mixed cropping, on the other hand, is mainly adopted to minimize risk under uncertain environmental conditions, as the failure of one crop can be compensated by another. Both systems help suppress weeds, reduce pest and disease incidence, and improve soil fertility, especially when legumes are included. Their adoption enhances productivity, sustainability, and resilience of agricultural systems.

Concept of Intercropping

Definition of Intercropping: Intercropping is a cropping system in which two or more crops are grown simultaneously on the same field in a definite row arrangement and proportion. The crops are selected and managed in such a way that they do not compete severely with each other but instead use available resources more efficiently than when grown separately.

Basic Principles of Intercropping: The basic principle of intercropping is the efficient and complementary use of resources such as light, water, nutrients, and space. Crops with different growth habits, rooting depths, and nutrient requirements are combined to reduce competition and increase overall productivity. Proper spatial arrangement, timely planting and balanced input management are essential to achieve maximum benefits from intercropping.

Common Examples of Intercropping: Common examples of intercropping include maize + cowpea,

maize + pigeon pea, sorghum + green gram, sugarcane + soybean, and cotton + black gram. In these combinations, cereals are often intercropped with legumes to improve soil fertility and enhance yield stability.

Objectives of Intercropping: The main objectives of intercropping are to increase total yield per unit area, make efficient use of land and resources, reduce the risk of crop failure, and improve soil fertility. Intercropping also aims to suppress weeds, reduce pest and disease incidence, and provide greater economic returns and sustainability compared to sole cropping systems.

Concept of Mixed Cropping

Definition of Mixed Cropping: Mixed cropping is a cropping system in which two or more crops are grown together on the same field without any definite row arrangement or fixed proportion. The crops are mixed and sown together, mainly to reduce the risk of total crop failure under uncertain climatic conditions.

Main Features of Mixed Cropping: The main features of mixed cropping include the absence of a specific row pattern, simultaneous sowing of different crops, and simple management practices. Crops are generally selected based on their ability to grow together and tolerate competition. Mixed cropping is less input intensive and is commonly practiced in rainfed and subsistence farming systems where risk minimization is more important than maximizing yield.

Examples of Mixed Cropping Systems: Examples

of mixed cropping systems include wheat + mustard, groundnut + sunflower, sorghum + pigeon pea, barley + gram, and pearl millet + green gram. These crop mixtures help ensure some yield even if one crop performs poorly.

Purpose of Adopting Mixed Cropping: The primary purpose of adopting mixed cropping is to reduce the risk of crop failure due to pests, diseases, or adverse weather conditions. It helps stabilize yield, ensures food security, and provides farmers with insurance against crop loss. Mixed cropping also contributes to better use of land and supports sustainable farming under low-input conditions.

Differentiation between Intercropping and Mixed Cropping

Intercropping and mixed cropping are two important multiple cropping systems but they differ in their approach and objectives. In intercropping, two or more crops are grown simultaneously on the same field in a definite row arrangement and fixed proportion, which allows better management of spacing, nutrients and other inputs. The main aim of intercropping is to increase total productivity through efficient and complementary use of resources, and the yield of each crop can be assessed separately. In contrast, mixed cropping involves growing two or more crops together without any specific row pattern or proportion, where seeds are mixed and sown together. The primary objective of mixed cropping is to reduce the risk of crop failure under uncertain environmental conditions rather than maximizing yield. Intercropping requires more

planning and management, while mixed cropping follows simpler practices and is mainly adopted in rainfed and subsistence farming systems.

Advantages of Intercropping and Mixed Cropping

Intercropping and mixed cropping offer several agronomic and economic advantages in farming systems. Both practices help in efficient utilization of land, light, water, and nutrients, resulting in higher overall productivity compared to sole cropping. They reduce the risk of complete crop failure because the presence of more than one crop ensures yield stability under adverse weather conditions. Intercropping and mixed cropping also help in suppressing weeds, lowering pest and disease incidence and reducing the need for chemical inputs. When legumes are included, these systems improve soil fertility through biological nitrogen fixation. In addition, they provide diversified produce, ensure better income security for farmers and support sustainable agriculture by maintaining soil health and ecological balance.

Agronomic Advantages: Intercropping and mixed cropping provide important agronomic advantages by ensuring efficient use of available resources such as land, light, water, and nutrients. Crops with different growth habits and rooting patterns utilize resources at different depths and times, which reduces competition and increases overall productivity. These systems also help in suppressing weeds by providing better ground cover and reducing open spaces. In addition, the presence of diverse crops

disrupts pest and disease cycles leading to lower pest incidence and reduced dependence on chemical control measures.

Economic Advantages: From an economic point of view, intercropping and mixed cropping help maintain yield stability even under unfavourable climatic conditions. The failure of one crop can be compensated by the yield of another, which reduces income fluctuations. These systems minimize production risk and provide more reliable returns making them particularly beneficial for small and marginal farmers.

Criteria for Assessing Yield Advantages

The yield advantage of multiple cropping systems over sole cropping is assessed using different biological and economic indices. Land Equivalent Ratio, or LER, measures how efficiently land is used in intercropping compared to monocropping. Crop Equivalent Yield converts the yield of component crops into the yield of a single reference crop. Relative Yield Total evaluates the combined performance of component crops. Monetary Advantage Index considers both yield and market price to assess economic benefit, while Area Time Equivalent Ratio accounts for both land and time used by different crops in a cropping system.

Significance of Yield Assessment in Multiple Cropping Systems

Yield assessment in multiple cropping systems is significant because it allows a clear comparison with sole cropping systems and helps determine the actual benefits of crop combinations.

It supports informed decision making by farmers in selecting suitable cropping systems based on productivity and profitability. Accurate yield assessment also helps in improving productivity per unit area and time, thereby contributing to sustainable and efficient agricultural production.

Conclusion

Intercropping and mixed cropping are important components of multiple cropping systems that contribute significantly to sustainable agricultural production. By growing more than one crop on the same land, these systems ensure efficient use of natural resources, improve soil health and enhance overall farm productivity. Intercropping focuses on planned crop combinations to maximize yield through complementary resource use while mixed cropping emphasizes risk reduction and yield stability under uncertain conditions. Both systems help farmers cope with climatic variability pest and disease pressure and economic uncertainty. The assessment of yield advantages using indices such as Land Equivalent Ratio, Crop Equivalent Yield, and Monetary Advantage Index provides a scientific basis for comparing multiple cropping systems with sole cropping. Overall, intercropping and mixed cropping play a crucial role in improving productivity per unit area stabilizing farm income and promoting sustainable and resilient agricultural systems.

References

Francis, Charles A. (1986). *Multiple Cropping Systems*. Macmillan Publishing Company.

- Andrews, D. J. and A. H. Kassam. (1976). The Importance of Multiple Cropping in Increasing World Food Supplies. *Multiple Cropping*, edited by R. I. Papendick *et al.*, American Society of Agronomy, pp. 1-10.
- Willey, R. W. (1979). Intercropping: Its Importance and Research Needs. Part 1: Competition and Yield Advantages. *Field Crop Abstracts*, 32 (1): 1-10.
- Lithourgidis, A. S., *et al.* (2011). Sustainable Production of Barley and Wheat by Intercropping Common Vetch. *Agronomy for Sustainable Development*, 31(4): 623-631.
- Vandermeer, John. (1989). *The Ecology of Intercropping*. Cambridge University Press.
- Gomez, K. A. and A. A. Gomez. (1984). *Statistical Procedures for Agricultural Research*. 2nd ed., John Wiley and Sons.

Farm Women: Occupational Hazards in Crop Production Activities

Nomula Prathyusha and Swetha Kodali

Abstract

Women play a crucial role in agricultural activities across India, contributing significantly to food production and rural livelihoods. However, their work exposes them to various occupational health hazards that often remain unrecognized. This article examines the major health risks faced by women agricultural workers, particularly musculoskeletal disorders caused by manual labor –Weeding and respiratory issues resulting from pesticide exposure. It highlights the need for awareness, preventive measures, and gender-sensitive interventions to safeguard the health of women working in the agricultural sector.

Introduction

Agriculture is one of the largest employment sectors for women in India. Women are involved in almost every stage of crop production, including sowing, weeding, and transplanting, harvesting, and post-harvest processing. Despite their significant contribution, women agricultural workers face numerous occupational health risks due to lengthy working hours, physically demanding tasks, and exposure to harmful chemicals. High Exposure to Organic dust and its health effects among workers has been investigated in numerous epidemiological and exposure assessment studies during the last three decades. Pulmonary damage risk is mainly associated with raising Livestock animals due to organic dust exposure. If once the major body part lung is damaged by organic dusts, regeneration of lungs to normal state is almost impossible.

Review of Literature

Several studies have highlighted the occupational health problems faced by women in agriculture. Research indicates that musculoskeletal disorders are highly prevalent among women engaged in manual weeding and transplanting due to awkward postures and repetitive movements. Studies also show respiratory illnesses linked to pesticide exposure. Manual weeding remains a common practice in Indian agriculture, particularly in North East India and Assam, due to factors such as unreliable labor and increasing wages (Yaka, 2017). This method is predominantly employed by small-scale and subsistence farmers with limited land holdings, exposing workers to various health risks including musculoskeletal disorders (MSDs) and general discomfort. These risks are often exacerbated by the design of traditional tools, such as hoes, sick-

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les, and weeding hooks, which do not always consider the ergonomic needs of users (Khayer *et al.*, 2019). The physical demands of weeding, involving manual handling of materials, often lead to musculoskeletal disorders (MSDs) such as lower back, shoulder, and upper limb strains and sprains. By applying ergonomic design to tools, workstations and processes, agricultural organizations can create safer, more sustainable work environments, helping to prevent work-related musculoskeletal disorders (Aptel *et al.*, 2002). Workers engaged in weeding mostly face several challenges affecting their well-being and productivity. Studies have highlighted issues such as musculoskeletal problems, exhaustion, and pain (Singh, 2007; Parvez, 2017). Extreme weather conditions, including heat stress in summer and cold in winter, further complicate their work, while the use of traditional tools and poor posture during weeding exacerbate these problems, leading to increased physical strain and musculoskeletal disorders (Burman *et al.*, 2020).

Discussion

The occupational hazards faced by women in agriculture are both physical and chemical in nature. Musculoskeletal disorders arise from prolonged bending and lifting, while respiratory issues result from pesticide exposure.

General Occupational Hazards for Women in farming

Musculoskeletal Disorders (MSDs): Extremely high prevalence due to prolonged stooping, bending, and squatting. High energy expenditure and exten-

sive working hours. Exposure to sun, dust, and toxic pesticides leads to allergies and chronic coughing. Cuts, wounds, and infections from traditional, old, poorly designed tools.

Major Health Risks during Specific Activities

Sowing: Continuous forward bending, kneeling, or squatting while dropping seeds. High incidence of backache, neck pain, and pain in hands/wrist.



Sunburns, skin allergies, and headaches are very common.

Transplanting: Prolonged bending and standing in waterlogged fields. Very difficult drudgery leading to chronic lower back, waist, and shoulder pain.



Numbness in hands/feet, urinary infections, and gynaecological issues due to long hours in water.

Manual Weeding: Constant squatting, stooping, or bending for long hour's causes severe pains in the lower back, neck/shoulders



and knee/joint degeneration. Blisters on palms, cuts, and scratches on hands/feet. Increased risk of infection from waterlogged, contaminated soil and skin contact with pesticides.

Harvesting and post harvesting: It involves using sharp, traditional tools, which result in frequent cuts, wounds, blisters, and scratches on hands, fingers, and palms. Handling crops, such as wheat or grains, leads

to exposure to dust, husks and mold, causing respiratory allergies, chest pain and throat infections. Exposure to dust and sun causes eye infections and redness. It occurs in fields previously treated with pesticides, leading to skin and respiratory issues.



Common issues face in agricultural activities

Prolonged, direct exposure to sunlight and high temperatures leads to dehydration, severe fatigue, heat exhaustion, and heatstroke. Contact with crops and weeds leads to contact dermatitis, skin itching, infections, and allergies. Women face increased risks of gynaecological problems, including menstrual dysfunction, irregular periods, and pelvic pain, high rates of anaemia, vitamin deficiencies and general fatigue are reported due to physically demanding work and, often, poor nutritional intake. Mostly harvesting occurs in fields previously treated with pesticides, leading to skin and respiratory issues.

Conclusion

Women agricultural workers face multiple occupational hazards affecting health and productivity. Addressing these requires awareness, ergonomic interventions, and supportive policies. Adopting ergonomic, women-friendly tools might reduce physical strain by up to 35-40 per cent. Using gloves, hats, and scarves, face masks reduces injuries and skin conditions. Education on correct working postures, such as, for example, avoiding long periods

of squatting, can reduce musculoskeletal pain.

References

- Aptel, M., Claudon, L. and Marsot, J. (2002). Integration of ergonomics into hand tool design: principle and presentation of an example. *International Journal of Occupational Safety and Ergonomics*, 8(1): 107-115.
- Yaka, V. and Tajuddin, A. (2017). Effect of operational parameters on the performance of walk behind engine operated weeder for upland crops. *International Journal of Current Microbiology and Applied Sciences*, 6(8): 803-809.
- Khayer, S. M., Patel, T. and Ningthoujam, B. (2019). Ergonomic postural and biomechanical analysis of manual weeding operation in agriculture using digital human models. *Smart Innovation*, 2: 451-462.
- Singh, S, Mathur, P. and Rathore, M. (2007). Weeders for drudgery reduction of women farm workers in India. *Journal of Agricultural Engineering*, 44(3): 33-38.
- Parvez, R., Lawrance, A. and Lata, S. (2017). Physical problems of farm women during weeding in rose field. *International Journal of Research in Economics and Social Sciences*, 7: 133-139.
- Burman, R. R., Joshi, P., ... and Singh, A. K. (2020). Quantification of drudgery and ergonomics assessment of weeding activity in vegetable production system. *The Indian Journal of Agricultural Sciences*, 90(3): 634-638.

Integrated Farming System in Dryland Agriculture: A Sustainable Approach for Enhancing Productivity and Livelihood Security

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Abstract

Dryland agriculture occupies a major share of cultivated land in India and supports a large proportion of small and marginal farmers; however, it is characterized by low and unstable productivity due to erratic rainfall, frequent droughts, poor soil fertility and limited external inputs. Conventional monocropping systems in dryland areas often fail to ensure sustainable income and livelihood security. In this context, the Integrated Farming System (IFS) has emerged as a viable and eco-friendly approach for enhancing productivity, profitability and resilience of dryland farming. IFS involves the systematic integration of crops, livestock, fodder, agroforestry, horticulture and allied enterprises within a single farm unit, enabling efficient resource utilization and recycling of farm wastes. In dryland ecosystems, IFS improves soil health, enhances water use efficiency, diversifies income sources and minimizes climatic risks. Research evidence from semi-arid and arid regions of India indicates that dryland IFS models significantly increase system productivity, net returns and employment generation compared to sole cropping systems. This article reviews the concept, components, mechanisms, research evidence, practical implications and limitations of integrated farming systems in dryland areas, highlighting their role in achieving sustainable and climate-resilient agriculture.

Introduction

Dryland agriculture plays a crucial role in Indian food security, accounting for nearly 60 per cent of the cultivated area and contributing substantially to the production of cereals, pulses and oilseeds. Despite its importance, dryland farming is highly vulnerable to climatic uncertainties such as erratic rainfall, prolonged dry spells and frequent droughts. Low soil organic matter, poor nutrient availability and limited access to irrigation further constrain crop productivity, resulting in unstable farm income and livelihood insecurity. Traditionally,

dryland farmers have relied on monocropping systems, which expose them to high production risks and crop failures during adverse weather conditions. In recent years, the increasing impact of climate change has intensified the need for sustainable farming approaches that can enhance resilience while ensuring economic viability. Integrated Farming System (IFS) has gained considerable attention as a holistic and sustainable strategy to address these challenges by integrating multiple farm enterprises and optimizing resource use.

Concept of IFS in Dryland Areas

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The Integrated Farming System is based on the principle that the by-products of one enterprise serve as inputs for another, creating a mutually beneficial and self-sustaining system. In dryland agriculture, the primary objective of IFS is risk reduction through diversification and efficient utilization of scarce natural resources. Dryland IFS emphasizes the integration of drought-tolerant crops with livestock, fodder production, agroforestry and allied enterprises such as poultry and beekeeping. Unlike specialized farming systems, IFS reduces dependency on a single source of income and ensures stability under variable climatic conditions. The recycling of crop residues, animal waste and tree litter improves soil fertility and moisture retention, which are critical for sustainable production in rainfed ecosystems.

Components of Dryland Integrated Farming System

The effectiveness of IFS in dryland areas depends on the careful selection and integration of suitable components:

Crop Component: Drought-tolerant crops such as sorghum, pearl millet, finger millet, pigeon pea, groundnut, cowpea and horse gram form the base of dryland IFS. Intercropping and crop rotation improve resource use efficiency and reduce risk.

Livestock Component: Sheep and goat rearing are highly suited to dryland conditions due to their adaptability, low water requirement and ability to utilize crop residues and grazing lands. Cattle also contribute to farm income and manure production.

Fodder Component: Fodder crops like stylo, hedge lucerne and fodder sorghum ensure feed availability and support sustainable livestock production.

Agroforestry and Horticulture: Integration of hardy fruit and multipurpose trees such as ber, aonla, custard apple and tamarind enhance land productivity and provides additional income during drought years.

Allied Enterprises: Poultry, beekeeping and vermicomposting supplement farm income with minimal investment and resource requirement.

Resource Recycling in Dryland IFS

Resource recycling is the backbone of integrated farming systems. Crop residues are utilized as livestock feed, animal dung and urine are converted into farmyard manure or compost, and tree litter contributes to soil organic matter. This internal nutrient cycling reduces dependence on chemical fertilizers, improves soil structure and enhances water-holding capacity, making dryland farming more sustainable and cost-effective.

Mechanisms for Improving Dryland Productivity

Integrated farming systems enhance productivity and resilience in dryland areas through multiple mechanisms:

Risk Diversification: Multiple enterprises ensure income stability even during years of crop failure.

Improved Soil Health: Continuous addition of organic matter improves soil fertility, microbial activity and moisture retention.

Efficient Water Use: Mulching, agroforestry and diversified cropping systems reduce evaporation

losses.

Employment Generation: The integration of livestock and allied enterprises provides year-round on-farm employment opportunities.

Climate Resilience: IFS buffers the impact of droughts and climatic variability.

Research and Field Studies

Increased Net Returns & Benefit-Cost Ratios

- ✓ In a long-term IFS study conducted at ICAR-Central Arid Zone Research Institute, Bikaner (Rajasthan) from 2019-2023, the rainwater harvesting-based IFS model integrating arable crops, horticulture, fodder, dairy, Vermicomposting and mushroom production achieved mean annual net returns of ₹1,79,899 with a benefit-cost (B:C) ratio of 2.40. Compared to conventional sole cluster bean and moth bean systems, this represented 5.6 to 6.2 times higher net returns and far superior profitability than sole cropping systems.
- ✓ A study on an IFS model in Telangana examining multiple crop-livestock-fodder systems over 2021-2023 showed that the best IFS models produced gross returns of ₹210,439 acre⁻¹ and net returns of ₹124,953 acre⁻¹ with a B:C ratio of 2.46, substantially higher than traditional rice-groundnut systems.

Productivity, Resource Efficiency & Resilience

- ✓ The Rajasthan IFS yielded a Cluster Bean Equivalent Yield (CEY) of 7608 kg ha⁻¹ under integrated systems compared to just 274 kg ha⁻¹ under conventional sole cropping, indicating

much higher productivity under dryland IFS.

- ✓ Integrated farming systems demonstrated higher water use efficiency (2.498 kg/m³) and reduced water footprints (400 L/kg), contributing to resilience in water-scarce conditions.

Improved Livelihoods & Employment

Studies in semi-arid Bundelkhand and other regions reported enhanced employment generation (e.g., IFS models yielding up to 336 man-days per year) and year-round income stability due to diversified outputs.

Benefits to Food Security & Nutrition

Research in Telangana highlighted that IFS models not only increased income but also diversified farm products (e.g., fodder, fruits, vegetables, livestock products), which contributes to improved household nutrition and food security compared with sole cropping systems. These diversified systems also helped smallholders buffer drought impacts by providing alternative sources of income and food.



Practical Applications and Implications

The adoption of integrated farming systems in dryland areas offers multiple benefits:

Economically Viable: Enhances farm income and profitability.

Environmentally Sustainable: Improves soil health and reduces external input dependency.

Socially Beneficial: Generates employment and improves livelihood security.

Climate-Smart: Enhances resilience to drought and climate change.

Dryland-specific IFS models, tailored to local resources and socio-economic conditions, can significantly improve the sustainability of rainfed agriculture.

Conclusion

Integrated Farming System represents a sustainable and climate-resilient approach for dryland agriculture. By integrating crops, livestock, agroforestry and allied enterprises, IFS optimizes resource use, improves soil health and ensures stable income under rainfed conditions. In the face of increasing climatic uncertainties and resource constraints, dryland IFS offers a holistic solution for enhancing productivity, profitability and sustainability of Indian agriculture.

Precision Weed Management: Smart Technologies for Sustainable and Efficient Agriculture

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Weeds continue to pose a significant threat to agricultural productivity, with estimated annual crop losses in India exceeding \$11 billion. Traditional weed control methods, manual, mechanical, biological and chemical, are increasingly proving inefficient, costly and environmentally harmful. The excessive reliance on herbicides has led to widespread herbicide resistance and environmental contamination. This scenario has necessitated the development of innovative approaches like Precision Weed Management (PWM), which offers a smarter, targeted and sustainable way to combat weeds.

What is Precision Weed Management?

Precision Weed Management (PWM) is a site-specific, data-driven method that identifies and treats only weed-infested zones within a crop field. Unlike conventional uniform spraying, PWM uses advanced tools such as sensors, drones, GPS and robotics to detect weeds and apply herbicides with remarkable accuracy. The technique is grounded in the understanding that weeds are often unevenly distributed and thus, precise mapping enables targeted intervention, reducing chemical use and improving ecological balance.

The Need for a New Paradigm of PWM

There are currently 539 unique cases (species x site of action) of herbicide resistant weeds globally,

with 273 species (156 dicots and 117 monocots). Weeds have evolved resistance to 21 of the 31 known herbicide sites of action and to 168 different herbicides. Herbicide resistant weeds have been reported in 102 crops in 75, traditional blanket-spraying approaches are increasingly ineffective (www.weedscience.org). Moreover, environmental regulations and public health concerns are driving the shift toward more sustainable practices. PWM provides a timely solution by:

- ✓ Minimizing herbicide use and environmental pollution.
- ✓ Reducing input costs for farmers.
- ✓ Enhancing long-term crop productivity.
- ✓ Supporting the fight against herbicide-resistant weed species.

Key Technologies in PWM

Weed Mapping and Detection: Using ground-based sensors, drones and satellites equipped with multispectral and hyperspectral cameras, PWM systems can accurately map weed locations.

Smart Sprayers and Robots: Devices such as Robovator, Hortibot and EcoRobot are capable of real-time weed detection and targeted herbicide application or mechanical removal.

Machine Learning and AI: Advanced algorithms differentiate between crops and weeds based on

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shape, spectral signature and texture.

Patch and Spot Spraying: Patch Spraying targets infested zones, saving up to 89% herbicides. Spot Spraying focuses on individual plants, allowing up to 99% reduction in herbicide usage.

Robotic Innovations: Robots like Ladybird, Boni-rob and RIPPA combine sensors, AI and mechanical or chemical weeders to operate autonomously with high accuracy and low labor input.



Advantages of Precision Weed Management

Resource Efficiency: Herbicides are used only where necessary, reducing waste.

Economic Benefits: Studies report up to 60% cost savings on herbicides.

Environmental Protection: Limits soil, water and air contamination.

Improved Public Perception: Reduces health hazards and increases acceptance of chemical use.

Enhanced Weed Control: Higher precision leads to more effective weed suppression.

Research conducted across India and Europe demonstrates the practical benefits of PWM: In Rice and Greengram Fields: Drone-based spraying reduced herbicide and water usage while increasing weed control efficiency and yield (Ramesh *et al.*, 2024).

In Soybean and Sugar Beet Fields: Precision

hoeing using automated steering led to an 87–89% weed reduction and significant yield increases (Kunz *et al.*, 2015).

Conclusion

Precision Weed Management represents a vital advancement in agricultural sustainability. By harnessing modern technology, PWM optimizes herbicide use, boosts farm profitability and protects the environment. As computing power, AI and robotics continue to evolve, the integration of PWM into mainstream farming will become not just beneficial but essential. The future of weed control lies in smart, adaptive and site-specific strategies that align with global sustainability goals.

References

- Chethan, C. R., Singh, P. K., Dubey, R. P., Mishra, J. S., Choudhary, V. K., Pawar, D. V. and Sreekanth, D. (2022). Precision weed management techniques: A smarter way to manage the weeds. *Intensive Agriculture*, 56: 4-8.
- Ramesh, T., Madhusree, S., Rathika, S., Meena, S. and Raja, K. (2024). Drone based herbicide application in greengram (*Vigna radiata*). *The Indian Journal of Agricultural Sciences*, 94(3): 329-332.
- Zhang, W., Miao, Z., Li, N., He, C. and Sun, T. (2022). Review of current robotic approaches for precision weed management. *Current Robotics Reports*, 3(3): 139-151.
- Choudhary, B. L., Gadhwal, R., Yadav, M., Dhayal, S. and Dadrwal, B. K. (2020). Role of PGPR in sustainable agriculture, *Krishiscience*.

- Kunz, C., Weber, J. F. and Gerhards, R. (2015). Benefits of precision farming technologies for mechanical weed control in soybean and sugar beet comparison of precision hoeing with conventional mechanical weed control. *Agronomy*, 5(2): 130-142.
- Bijarnia, S. L., Bijarnia, H. K., Dadarwal, B. K. and Choudhary, P. (2020). Sustainable Crop Production through Zero Budget Natural Farming. *Agriculture and Food: e-Newsletter*



Sustainable Production through Biostimulants in Fruit Crops

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Introduction: Need for Sustainable Intensification in Fruit Crops

Fruit production systems worldwide are facing increasing challenges arising from climate change, soil degradation, escalating input costs, and stricter demands for food quality and environmental safety. Fruit crops are long-duration, high-value enterprises where yield stability, uniformity, shelf life, and appearance directly influence profitability. Conventional reliance on synthetic fertilizers and chemical inputs has led to declining soil health, inefficient nutrient use, and environmental concerns. Sustainable intensification in fruit crops therefore requires approaches that enhance plant efficiency and resilience rather than simply increasing input use. In this context, plant biostimulants have emerged as promising tools to improve productivity while maintaining ecological balance.

Concept and Definition of Plant Biostimulants

Plant biostimulants are substances or micro-organisms of biological origin that, when applied to plants or the rhizosphere, stimulate natural physiological processes to enhance nutrient use efficiency, abiotic stress tolerance, and crop quality traits, regardless of their nutrient content. This definition clearly distinguishes biostimulants from

fertilizers and pesticides. Unlike fertilizers, which primarily supply nutrients, and pesticides, which control pests and diseases, biostimulants act by modulating plant metabolism, hormone signaling, root development, and plant-microbe interactions. Regulatory frameworks also emphasize their role in stimulating plant nutrition processes and improving nutrient availability in the rhizosphere, making them central to sustainable horticultural practices.

Importance of Biostimulants in Fruit Crop Production

The significance of biostimulants is particularly pronounced in fruit crops due to their perennial nature and sensitivity to environmental stresses. Even small improvements in flowering, fruit set, stress tolerance, or quality parameters can result in substantial economic benefits. Biostimulants enhance root growth, improve canopy health, synchronize flowering, reduce fruit drop, and accelerate recovery from stress conditions such as drought, heat, and salinity. Additionally, improvements in fruit firmness, color, sugar content, acidity balance, and bioactive compounds contribute to higher market acceptance and reduced post-harvest losses, thereby strengthening the overall sustainability of fruit production systems.

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Major Categories of Biostimulants Used in Fruit Crops

Seaweed and Botanical Extracts: Seaweed extracts derived from marine algae such as *Ascophyllum nodosum* and *Ecklonia maxima* are widely used biostimulants in fruit crops. These extracts contain bioactive compounds including polysaccharides, betaines, micronutrients and hormone-like substances that influence plant growth and stress responses. Applied as foliar sprays or through fertigation, seaweed extracts enhance flowering, fruit set, antioxidant activity, and tolerance to abiotic stresses. Their effectiveness is closely associated with correct timing, particularly during pre-flowering, fruit set, and stress-prone growth stages.

Humic and Fulvic Substances: Humic substances, including humic and fulvic acids, play a vital role in improving soil-plant relationships. These compounds enhance soil structure, increase cation exchange capacity, stimulate root proliferation, and improve nutrient availability and uptake. In fruit orchards, soil or fertigated application of humic substances improves nutrient use efficiency and sustains root activity, especially in soils with low organic carbon or salinity issues. Their ability to stimulate soil microbial activity further supports long-term soil fertility and orchard sustainability.

Protein Hydrolysates and Amino Acid-Based Biostimulants: Protein hydrolysates consist of peptides and amino acids that serve as building blocks for enzymes, proteins, and stress-response compounds. These biostimulants enhance metabolic

efficiency, support rapid stress recovery, and improve photosynthetic performance. In fruit crops, foliar or fertigated application of protein hydrolysates is particularly beneficial during high-demand stages such as flowering and fruit development, leading to improved yield and quality parameters.

Microbial Biostimulants: Microbial biostimulants include plant growth-promoting rhizobacteria (PGPR) such as *Bacillus*, *Pseudomonas*, and *Azospirillum*, as well as arbuscular mycorrhizal fungi and beneficial fungi like *Trichoderma*. These microorganisms enhance nutrient acquisition, particularly phosphorus and micronutrients, improve root health, and increase tolerance to drought and salinity. Their application at planting, through nursery dips, or via drip irrigation establishes beneficial symbioses that persist across seasons, contributing to sustained productivity and improved soil health.

Other Natural Compounds: Other biostimulants such as chitosan, silicon, and biopolymers function as elicitors and structural enhancers. Chitosan primes plant defense mechanisms, enhances tolerance to abiotic stress, and improves fruit firmness and shelf life in certain crops. These compounds are particularly valuable in residue-safe and integrated production systems focused on reducing post-harvest losses.

Benefits of Biostimulants in Sustainable Fruit Production

The integration of biostimulants into fruit production systems offers multiple benefits. Improv-

ed nutrient use efficiency reduces fertilizer losses and input costs. Enhanced tolerance to environmental stresses stabilizes yield under variable climatic conditions. Improved soil biological activity and structure contribute to long-term sustainability of orchard systems. Furthermore, improved fruit quality attributes such as size, color, firmness, and shelf life directly enhance market value and reduce post-harvest losses. These benefits make biostimulants well suited for organic farming, integrated nutrient management and climate-resilient horticulture.

Crop-Specific Applications of Biostimulants

In mango, biostimulants are commonly applied before flowering to support panicle emergence and stress mitigation, and during fruit set to reduce early fruit drop and improve retention. In banana, humic substances and microbial inoculants applied to the root zone enhance nutrient uptake and root vigor, supporting bunch development. Grapes respond well to biostimulant application at pre-bloom and post-set stages for improved berry set and uniform clusters, while stress-mitigation sprays protect photosynthesis during heat stress. In citrus, biostimulants support flush growth, root activity, and rind quality, thereby reducing post-harvest losses. Strawberry and other berry crops benefit from microbial inoculants at planting and foliar biostimulants during flowering and fruiting to improve root establishment, fruit uniformity, and firmness.

Best Practices: Do's and Don'ts in Biostimulant

Use

For effective use, biostimulants should be selected based on clear composition, credible research evidence and crop-specific recommendations. Application should coincide with responsive growth stages such as establishment, flowering, fruit set, and stress periods. Biostimulants must complement, not replace, sound agronomic practices such as balanced fertilization, proper irrigation, and canopy management. Overuse, improper mixing, or reliance on biostimulants to correct major nutrient deficiencies should be avoided. On-farm trials with treated and untreated comparisons across seasons are essential to evaluate consistent performance.

Conclusion

Biostimulants are not miracle inputs, but when used strategically, they are powerful tools for sustainable fruit production. By enhancing nutrient efficiency, strengthening root systems, increasing tolerance to abiotic stresses, and improving fruit quality, biostimulants enable higher marketable yields with optimized input use. Their integration with good orchard management practices supports resilient, profitable, and environmentally responsible fruit production systems, making them increasingly important in modern horticulture.

References

- du Jardin, P. (2015). Plant biostimulants: Definition, concept, main categories and regulation. *Scientia Horticulturae*, 196: 3-14.
- European Union. (2019). Regulation (EU) 2019/1009 of the European Parliament and of the

Council of 5 June 2019 laying down rules on the making available on the market of EU fertilising products. *Official Journal of the European Union*.

Gonçalves, B., *et al.* (2025). Biostimulants in fruit crop production: Impacts on growth, yield, quality, and resilience. *Horticulturae*, 11(12): 1452.

Rouphael, Y. and Colla, G. (2020). Editorial: Biostimulants in agriculture. *Frontiers in Plant Science*, 11: 40.

Rouphael, Y. and Colla, G. (2020). Toward a sustainable agriculture through plant biostimulants: From experimental data to practical applications. *Agronomy*, 10(10): 1461.

Mughunth, R. J., *et al.* (2024). A review of seaweed extract's potential as a biostimulant to improve growth, yield, and quality in horticultural crops. *Scientia Horticulturae*.

Zulfiqar, F., *et al.* (2024). Biostimulants: A sufficiently effective tool for sustainable agriculture under environmental stresses. *Comptes Rendus Biologies*.

Climate Smart Agriculture: The Path to Sustainable Food Security

Ritika Grover and Deepa Sharma

Abstract

Climate-smart agriculture is a holistic approach that helps farming systems adapt to the growing challenges of climate change while securing food, nutrition and livelihoods. It rests on three pillars: improving productivity to meet rising food demand, building resilience so farmers can withstand droughts, floods and pests and lowering agriculture's contribution to greenhouse gas emissions. It blends modern innovations such as improved seed varieties, efficient irrigation and digital tools with traditional wisdom that has sustained farming communities for generations. It is not just a strategy for survival, but a promise of hope, ensuring that agriculture continues to nourish both people and the planet in the face of a changing climate.

Introduction

Imagine being a farmer who wakes up every day unsure if the rain will come, if the heat will scorch your crops or if a sudden flood will wipe out everything you've planted. This is now a daily reality for millions of farmers across the world, especially in countries like India, where agriculture is deeply tied to nature and weather. As climate change becomes more intense, farming has become riskier, more unpredictable and far less secure. Global climate change significantly threatens agricultural productivity, food security and environmental sustainability. Balancing the need to reduce greenhouse gases with growing enough food to feed more people is one of the toughest challenges we face today. Human activities such as industrialization and deforestation have increased the levels of green-

house gases in the atmosphere. Agriculture is a major contributor to greenhouse gas emissions, responsible for over a 25 per cent of the total emissions caused by human activities worldwide. This happens because when soil breaks down organic material or farmers burn leftover crops, carbon dioxide is released. Climate-Smart Agriculture (CSA) has emerged as a powerful solution that focuses on helping farmers adapt to climate risks while also reducing their carbon footprints. CSA is not one single method. It's a mix of smart practices: using water more efficiently, growing crops that can handle drought or floods, improving soil health and reducing pollution from farming. Climate smart agriculture is the bridge between today's farming changes and tomorrow's food security. It ensures that every smart choice in the field not only protect

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the crop but also nurtures the soil, saves water and lowers the negative effects of farming on the environment.

Principles of Climate Smart Agriculture

The foundation of Climate Smart Agriculture rests on three powerful and interconnected pillars defined by the FAO, each designed to secure food systems, protect livelihoods and safeguard the planet in the face of an unpredictable climate. These principles are not just guidelines but are a roadmap for transforming agriculture into a force that can feed the world while healing the environment.

Sustainably increase productivity: Produce more food from the same land while using fewer resources.

Enhance adaptation and resilience: Help farmers and crops withstand climate stresses like drought, floods, heat waves and shifting pests and disease patterns.

Reduce greenhouse gas emissions (Mitigation): Use of sustainable agricultural practices to lower down the emission of greenhouse gases and reduce the carbon footprint.

Climate Change and Crop Production

Climate change poses serious risks to crop production but with scientific solutions and sustainable practices we can reduce its impact. Crop production and climate change are closely linked. On one hand, changes in the climate such as rising temperature, irregular rainfall, drought and floods which makes it difficult for the farmers to grow good quality crops. These changes can reduce yields, increase pests and damage the soil. On the other

hand, some farming practices also add to climate change. For example, using too many chemical fertilizers, cutting down forests for farmland and growing crops like rice (which releases methane) all produce greenhouse gases that warm the planet. So, farming is both affected by climate change and also contributes to it. That's why we need smart and sustainable farming methods that protect the environment and help farmers grow crops even in the changing weather.

To effectively address these challenges, it is essential to equip the farmers with climate resilient seeds and varieties that can survive drought, heat or even floods. Good water management like using drip irrigation or rainwater harvesting help to save water during dry spells. Taking care of soil is equally important. Simple practices like adding compost or rotating crops can keep the soil healthy and productive. Providing farmers with affordable loans or government support can make a big difference, especially for small farmers who struggle to afford new technologies.

Impacts of Climate Change on Agricultural Yields and the Urgent Need for Adaptive Strategies

Increased concentration of carbon dioxide: Carbon dioxide can be both a blessing and a challenge for plants. On one hand, it is a vital ingredient for growth. When CO₂ levels rise in C₃ crops like wheat, rice and soybeans, plants are often more vigorous and sometimes with 30-50% more biomass and greater root and shoot development.

In case of C_4 plants, like corn, sugarcane, and millet. These crops already use CO_2 very efficiently, so adding more CO_2 to the air doesn't help them much. But during dry periods, they lose less water and can handle drought better than C_3 plants.

Temperature alterations: Rising temperatures due to climate change are creating serious challenges for agriculture worldwide. Higher temperatures speed up the growth of many crops but this faster development often shortens the time plants have to fully mature resulting in smaller yields. Sudden heat waves during critical stages such as flowering and grain filling can disrupt pollination and reduce grain quality. On a cellular level, excessive heat creates stress by generating harmful reactive molecules that interfere with photosynthesis and other vital processes. While plants have natural defense mechanisms like heat-shock proteins, prolonged or extreme heat can overwhelm these systems, impairing plant growth and productivity.

Unpredicted rainfall: Climate change is expected to bring more extreme weather events. Even if the total rainfall in a year does not change much, the intensity and frequency of heavy rains, hailstorms and floods are likely to increase. These can damage crops directly, delay planting and harvesting or can cause waterlogging. On the other hand, prolonged dry spells and droughts can lead to complete crop failure, leaving farmers without income or food.

Pests: Climate change changes the way plants and pests interact, and this can vary from place to place and over time. When plants are already stressed by

extreme weather, they become more vulnerable to pests and diseases. Another challenge arises when pests move into areas where their natural predators are absent, making biological control less effective unless new predator species establish themselves. The extent of crop damage will depend on many factors, such as how pest populations change, the diversity of insect species, how plants and herbivores interact and the survival of natural enemies, possible extinctions and how effective crop protection methods remain in the future.

Shrinkage in agricultural land: The shrinkage of agricultural land is an emerging concern for global food security. Rapid urbanisation, industrial expansion, soil degradation, and climate change are steadily reducing the amount of land available for farming. Rising sea levels and coastal flooding also threaten fertile low-lying farmlands. The shifting rainfall patterns and extreme weather events are making some areas unsuitable for cultivation, forcing farmers to abandon their fields. As agricultural land shrinks, the pressure to produce more food on less land increases, making it essential to adopt sustainable intensification methods, restore degraded soils, and protect existing arable areas from further loss.

Climate Smart Practices in Agriculture

Water Smart Practices

Drip irrigation: Delivers water directly to plant roots, reducing losses from evaporation and runoff.

Sprinkler systems: Distribute water evenly across fields and is useful for uneven terrain.

Mulching: Covers the soil with crop residue or organic material to lock in moisture and keep roots cool.

Rainwater harvesting: Stores water in tanks or ponds for use during dry periods. Scheduling irrigation using weather forecasts or soil moisture sensors: avoids overwatering and saves energy.

Soil Health Management

- ✓ Adding organic matter through compost, farm-yard manure or green manures to boost fertility and improve texture.
- ✓ Conservation tillage or zero tillage to reduce soil disturbance, preventing soil erosion and preserving soil biodiversity.
- ✓ Cover cropping to shield soil from heat, heavy rain and nutrient loss while fixing nitrogen naturally.
- ✓ Contour farming and bunding to prevent water runoff on slopes.
- ✓ Balanced nutrient management using soil tests and integrating biofertilizers like *Azotobacter* and phosphate-solubilizing bacteria.

Climate Resilient Crop Practices

- ✓ Drought tolerant varieties which can withstand water scarcity and high temperatures.
- ✓ Flood tolerant varieties which can survive waterlogging in heavy rainfall areas.
- ✓ Short duration crops which matures quickly to avoid late season heat or floods.
- ✓ Pest and disease resistant varieties which reduces the crop losses and chemical use.
- ✓ Locally adapted varieties perform well under

regional climate and soil conditions.

Protected Cultivation: In climate smart agriculture, protected cultivation acts like a safety net for crops. By using structures such as polyhouses, shade nets and low tunnels farmers can shield plants from extreme heat, heavy rains, frost and strong winds which are becoming common with climate change. With protected cultivation, farmers can grow high value crops in off season and fetch better market prices.

Nutrient Smart Practices: In climate smart agriculture, effective nutrient management is all about feeding crops in the smartest possible way that is giving them the right nutrient, at the right time, and in the right amount. Using fertilizers carefully keep crops healthy, lower the cost for farmers and reduces the pollution and greenhouse gas emission that comes from overuse.

Role of Technology and Innovation in Climate Smart Agriculture

Technology and innovation are the backbone of climate smart agriculture, giving farmers new ways to adapt, protect their crops and make smarter decisions in an unpredictable climate. From mobile apps to advanced breeding techniques, these tools are helping agriculture grow from guesswork to precision and turn uncertainty into plan of action.

Digital Agriculture and IoT: Digital tools and the Internet of Things (IoT) are putting real time insights into farmers' hands. The use of soil sensors help measure moisture levels to the exact percentage, drones can spot early signs of pest damage and auto-

mated irrigation systems deliver water only when and where it is needed which helps save both resources and cost.

Weather forecasting tools: Today's forecasting tools use satellites, AI and hyper local data to provide farm specific alerts on rainfall, temperature shifts and extreme events. Farmers can now plan sowing, irrigation and harvesting with greater accuracy, minimizing losses and avoiding climate related surprises.

Climate Resilient Crop Breeding: through advanced breeding techniques, scientists are developing crop varieties that can thrive despite droughts, floods or heat waves. The goal is not just survival but stability. When farmers plant these resilient varieties, they are not only protecting their harvests but also securing food supplies for communities and reducing climate shocks. In many ways, every seed of a climate resilient crop is like a small shield helping agriculture stand strong in a world where the weather is becoming more unpredictable.

Government Initiatives on Climate Smart Agriculture

- ✓ The National Adaptation Fund for Climate Change, National Innovation on Climate Resilient Agriculture, Soil Health Mission, Pradhan Mantri Krishi Sinchayee Yojna, Parampragat Krishi Vikas Yojna and Climate Smart Village are few examples of government initiatives in India focusing on CSA.
- ✓ There are various public and private organizations like the farmer-producer organization and

NGO that are working towards the adoption of CSA.

- ✓ The CGIAR Program on Climate Change and Food Security (CCAFS) is a global partnership of various research organizations that addresses the interlinked challenges of food security, poverty and climate change.
- ✓ The Global Alliance for Climate Smart Agriculture is a voluntary organization that brings together government, farmers, research institutions and private sector to gather information, policy making and investment in CSA.
- ✓ The Climate Smart Agriculture Youth Network (CSAYN) is a group of young people from different countries who are promoting CSA awareness among youth and stakeholders.

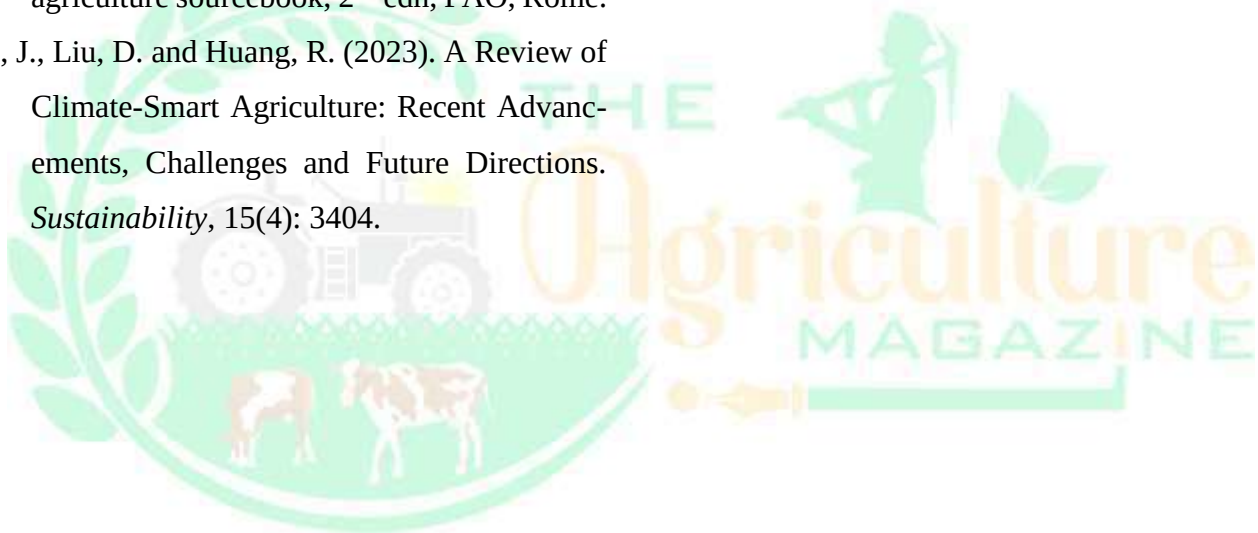
Conclusion

Climate-smart agriculture is more than a set of practices; it's a promise to farmers that they won't face the challenges of the changing climate alone. By combining innovation, traditional wisdom and sustainable resource management, it helps them protect their harvests, livelihoods and dignity. It's about securing food for tomorrow while safeguarding the land, water and ecosystems we depend on today, ensuring that farming remains not just a profession, but a legacy for generations to come. At its core climate smart agriculture is all about strength and adaptability, ensuring farmers stay productive, consumers stay nourished and the ecosystem stay healthy. It turns uncertainty into

opportunity, providing that agriculture can grow stronger even in the face of climate change.

References

- Chauhan, A. S., Rani, A., Kumari, A. and Singh, R. N. (2021). Climate-Smart Agriculture: An Integrated Approach for Attaining Agricultural Sustainability. *Climate Change and Resilient Food Systems*. Springer. pp. 141-189.
- FAO (Food and Agriculture Organization of the United Nations). 2017. *Climate-smart agriculture sourcebook*, 2nd edn, FAO, Rome.
- Zhao, J., Liu, D. and Huang, R. (2023). A Review of Climate-Smart Agriculture: Recent Advancements, Challenges and Future Directions. *Sustainability*, 15(4): 3404.



Wild Bee Pollinators and their Vital Role in Agriculture

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Wild bees are incredibly diverse. Scientists estimate there are over 20,000 species worldwide, many of which are essential for pollinating both wild plants and crops. Unlike honey bees, which live in large colonies, many wild bees are solitary. Some, like bumble bees and sweat bees, form small social groups, but most make nests alone in soil, hollow stems, or abandoned beetle holes in wood. Wild bees come in all shapes, sizes, and colors from fuzzy, yellow-and-black bumble bees to metallic green sweat bees and leafcutter bees. Each species has its own unique way of collecting nectar and pollen, often specializing in certain types of flowers. For instance Megachile bees are highly efficient pollinators because they carry large amounts of pollen on their abdomen.

Why Wild Bees Matter

Wild bees are not just backups for honey bees they often pollinate plants that honey bees cannot. Certain crops such as alfalfa, sesame, sunflower, safflower, and many pulses rely heavily on wild bees. Some wild bees perform “buzz pollination”, vibrating their bodies to release pollen from flowers

like tomatoes, eggplants, and peppers something honey bees cannot do. Wild bees also enhance the efficiency of honey bees. When wild bees and honey bees forage together, honey bees move between flowers more effectively, resulting in better fruit and seed set. In crops like almonds and blueberries, wild bees have been shown to double fruit yields compared to areas with honey bees alone.

Pollination and Food Security

Pollinators are critical to global food production. About 75-80% of cultivated crops depend on animal pollination, and declining honey bee populations have increased the importance of wild bees. Without them, many crops would see lower yields, threatening food security. Wild bees contribute not only to agricultural productivity but also to the preservation of wild plants and overall ecosystem health. By ensuring diverse pollination, they maintain the genetic diversity of plants, which is vital for resilient landscapes.

Conservation of Wild Bees

Despite their importance, wild bees face many threats. Habitat loss, climate change, pesticide

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use, pollution, diseases, and invasive species have all contributed to declining populations. Some species, like the rusty-patched bumble bee, are now considered endangered. Conserving wild bees requires a combination of habitat protection and mindful agricultural practices. Planting native and flowering plants, avoiding pesticide use during peak pollinator activity, and creating artificial nesting sites such as bee hotels can support healthy wild bee populations. Using pesticides in the evening, when bees are less active, can also reduce harmful effects.

Conclusion

Wild bees are nature's unsung heroes. Their role in pollination is invaluable yet often overlooked. By promoting awareness, planting pollinator-friendly plants, and supporting conservation efforts, we can protect these vital insects and ensure the sustainability of our crops, gardens, and natural ecosystems.