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Speed Breeding: Growing More Crops in Less Time

Article ID: 73500

Pruthviraj, G.[1], Devi Sri, D.[2], Sabbarigari Sai Vamshi[3], Rupali Gupta[4]

[1]Ph.D. Scholar, Department of Genetics and Plant Breeding, UAS, Dharwad.

[2]Ph.D. Scholar, Department of Plant Breeding and Genetics, OUAT, Bhubaneshwar.

[3]Ph.D. Scholar, Department of Genetics and Plant Breeding, College of Agriculture, PJTAU, Rajendranagar, Hyderabad.

[4]Ph.D. Scholar, Department of Genetics and Plant Breeding, College of Agriculture, IGKV, Raipur, 492012.

Summary

Speed breeding is a modern technique that accelerates plant growth and reduces the time required for crop improvement. By manipulating environmental conditions such as light, temperature, and photoperiod, this technique enables multiple crop generations within a single year, significantly surpassing the limitations of conventional breeding methods. The integration of speed breeding with advanced genetics tools, including CRISPR and marker-assisted selection, has further enhanced its potential to develop high-yielding, disease-resistant, and climate-resistant crop varieties. This approach is particularly relevant in the context of global food security and climate change, where rapid development of improved cultivars is essential. Although the requirement for controlled environments and technical expertise poses certain challenges, ongoing advancements are making the technology increasingly accessible. Overall, speed breeding represents a transformative strategy in plant breeding, offering a faster and more efficient pathway to meet the growing food demands of the world.

Introduction

Feeding a rapidly growing population is one of the greatest challenges of the 21st century. With changes in climate, shrinking arable land, and increasing food demand, traditional crop improvement methods often seem too slow to keep pace. In this context, a revolutionary approach known as speed breeding is gaining global attention for its ability to accelerate crop production and breeding cycles.

Speed breeding is a modern technique that allows scientists and breeders to grow multiple generations of crops within a single year. Normally, crops like pigeonpea or cotton take several months to complete one life cycle. However, under accelerated crop breeding conditions – using controlled environments with extended light periods, optimized temperature, and precise nutrient supply- plants grow faster and flower earlier. This enables researchers to achieve up to four to six generations per year instead of just one or two generations (Hickey *et al.*, 2019).

The idea of speed breeding was partly inspired by early controlled-environment plant studies, including those conducted by NASA (Ghosh *et al.*, 2018). This technique is based on manipulating environmental factors which significantly reduces the vegetative phase of each generation by promoting accelerated flowering, rapid seed maturation, and the overcoming of post-harvest dormancy, thereby enabling multiple successive cultivation cycles within a short period. When combined with controlled environments such as greenhouses or growth chambers, speed breeding creates optimal conditions for continuous and rapid crop advancement.

Speed Breeding Vs. Conventional Breeding

Features	Speed breeding	Conventional breeding
Generations / year	2 - 4 generations	1-2 generations
Time to release a variety	5 -7 years	10-15 years
Generation time	2 - 3 months	4- 6 months or more
Growing conditions	Controlled environment	Natural field conditions
Photoperiod	Artificially managed	Natural day length
Growth and flowering	Early flowering and rapid growth	Genotype and season dependent
Selection efficiency	High	Moderate to low

One of the biggest advantages of speed breeding is its potential to fast-track the development of improved crop varieties. Plant breeders can quickly select desirable traits such as higher yield, disease resistance, and climate resilience. This is particularly important in today's scenario, where new crop varieties are urgently needed to cope with changing environmental conditions. Speed breeding also complements modern genetic tools such as CRISPR and marker-assisted selection. When combined, these technologies can significantly reduce the time required to develop and release new varieties. What once took a decade can now be achieved in just a few years, making crop improvement more efficient and responsive.

In countries like India, where agriculture plays a vital role in livelihoods, speed breeding holds immense promise. It can help develop improved varieties of staple crops like rice, wheat, and pulses in a short time, thereby enhancing food security and farmer income. Moreover, it can be a valuable tool for research institutions and agricultural universities aiming to accelerate their breeding programs.

Applications of Speed Breeding in Major Crops

Rice: Rice breeding has advanced with Rapid Generation Advancement (RGA) and the Speed-Flowering protocol. At International Rice Research Institute, RGA improved flowering time and yield traits. The Speed-Flowering protocol (Kabade *et al.*, 2023) boosts breeding efficiency. It enables 4–5 generations per year under controlled conditions, accelerating cultivar development.

Wheat: Schoen *et al.*, (2022) enhanced a speed breeding technique for winter wheat, demonstrating that a 22-hour photoperiod combined with temperatures of 25°C/22°C significantly accelerated seed production, enabling up to four generations within a year.

Pigeonpea: Breeding pigeonpea is slow due to photoperiod sensitivity, often taking 12–13 years for variety release, as flowering occurs only under short-day conditions. Speed breeding overcomes this by optimizing photoperiod, light quality, temperature, and crop management, with a 13 h: 8 h: 13 h light regime and far-red light promoting early flowering. This approach enables 2–4 generations per year, reducing the breeding cycle to 2–4 years while improving selection efficiency (Gangashetty *et al.*, 2024).

Soybean: Soybean breeding is limited by its short-day photoperiod sensitivity, which delays flowering and generation turnover. LED-based photoperiod manipulation helps overcome this constraint, enabling faster growth and multiple generations per year.

Despite its advantages, speed breeding also has certain limitations. It requires controlled environment facilities, reliable electricity, and technical expertise, which may not be readily available in all regions. However, as technology advances and costs decrease, it is expected that this method will become more accessible in the near future.

Conclusion

Speed breeding represents a powerful innovation in modern agriculture. By reducing the time required for crop improvement, it offers a practical solution to meet the increasing food demands of the world. By handling the photoperiod regime and managing temperature conditions, researchers can use speed breeding technique to quickly improve numerous crops like wheat, barley, pea, canola, and chickpea. Combining it with advanced methods like genomics-assisted breeding and better systems for fast commercialization can help recover the extra costs. Although speed breeding techniques can be expensive and demand specialized infrastructure and expertise, they offer substantial potential to accelerate conventional breeding programs and enable the rapid development of stable, homozygous genotypes. As we move towards a future shaped by science and sustainability, speed breeding stands out as a promising tool to ensure food security and agricultural resilience.

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A Brief Insight on Seed Production Technology of Maize

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Sankar Lal Choudhary[1], Chanda Kumari Lakhran[2]
[1]M.Sc. (Ag.) Seed Science and Technology, Young Professional-II, ICAR-Indian Institute of Maize Research, Ludhiana, Punjab (Cluster- Chittorgarh, Rajasthan).
[2]M.Sc. (Ag.) Plant Physiology, Department of Plant Physiology, SKNAU, Jobner, Jaipur, Rajasthan.

Abstract
Maize (Zea mays L.) is one of the most important cereal crops globally, serving as a staple food, feed, and industrial raw material. The success of maize cultivation largely depends on the availability of high-quality seed with superior genetic purity and vigour. Seed production technology in maize is inherently complex due to its cross-pollinated nature and protandrous flowering behaviour. Scientific management practices such as isolation, detasselling, roguing, synchronization of flowering, and strict adherence to certification standards are essential to ensure seed quality. This review provides an extensive and detailed account of maize seed production technology, covering biological basis, types of seed production, agronomic practices, hybrid seed production methodologies, seed certification, post-harvest handling, and emerging advancements, with special emphasis on maintaining genetic purity and achieving high seed standards.

Introduction
Maize (Zea mays L.) is a versatile cereal crop cultivated across diverse agro-climatic regions. It plays a pivotal role in food security, livestock feed, and industrial applications such as starch, biofuel, and processed food industries. Unlike self-pollinated crops, maize is predominantly cross-pollinated due to its monoecious floral structure and protandry, where tassels shed pollen before silk emergence. This biological feature enhances genetic variability but poses a significant challenge in maintaining varietal purity during seed production. The advent of hybrid maize technology has significantly enhanced productivity worldwide, making seed production a highly specialized and economically important enterprise. Hybrid vigor or heterosis in maize results in improved yield, stress tolerance, and adaptability, but requires meticulous seed production practices to preserve genetic integrity.

Biological Basis of Seed Production in Maize
Understanding the floral biology of maize is fundamental for efficient seed production. The crop exhibits a monoecious flowering system with separate male (tassel) and female (ear) inflorescences on the same plant. The tassel produces large quantities of lightweight pollen grains that are dispersed by wind, while the silks emerging from the ear act as receptive structures for pollen. Protandry in maize ensures that pollen shedding typically occurs 2–3 days before silk receptivity, thereby promoting cross-pollination. Each silk corresponds to a potential kernel, and successful fertilization depends on viable pollen reaching receptive silks within a limited time window. Environmental factors such as temperature, humidity, and wind velocity significantly influence pollination efficiency and seed set (Copeland and McDonald 1995).

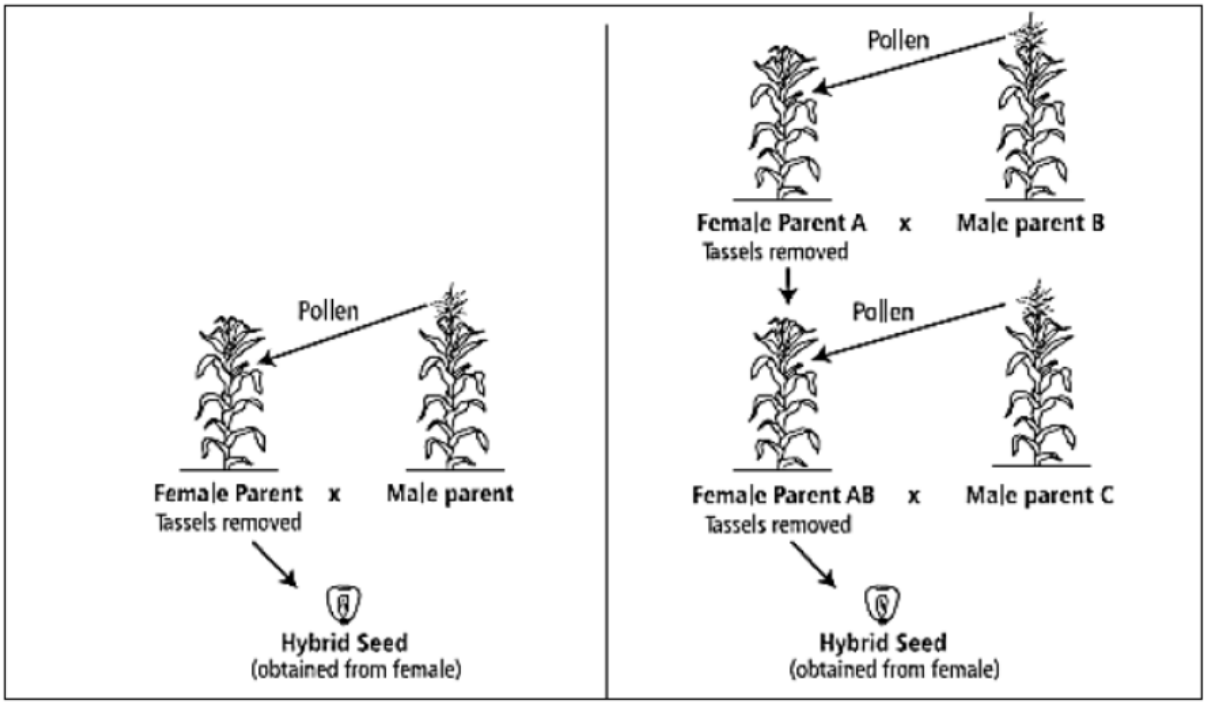
Importance of Quality Seed in Maize Production
Quality seed is a critical determinant of crop performance and productivity. In maize, the use of certified hybrid seed can increase yield potential by 20–30% compared to traditional varieties. Seed quality encompasses genetic purity, physical purity, physiological vigor, and seed health. Poor-quality seed can lead to reduced germination, uneven crop stand, susceptibility to diseases, and ultimately lower yields.

Genetic purity is particularly crucial in hybrid maize, as even minor contamination can significantly reduce heterosis and crop performance. Therefore, strict adherence to seed production protocols is essential to maintain seed quality (Tunwar and Singh 2015).

Types of Seed Production in Maize
1. Varietal Seed Production: Varietal seed production involves open-pollinated varieties (OPVs), synthetics, and composites. These varieties are maintained through controlled open pollination under prescribed isolation distances. Although they offer lower yield compared to hybrids, they provide stability and adaptability under marginal conditions.

2. Hybrid Seed Production: Hybrid seed production is based on controlled crossing between genetically distinct inbred lines. Depending on the parental combinations, hybrids are classified into single cross, double cross, three-way cross, and top cross hybrids. Among these, single cross hybrids are widely preferred due to their uniformity and superior yield potential. Hybrid seed production requires careful planning of parental line multiplication, synchronization of flowering,

and prevention of self-pollination in female lines through detasselling or use of male sterility systems (MacRobert et al. 2014).



Principles of Maize Seed Production

The success of maize seed production depends on several fundamental principles that ensure genetic purity and seed quality.

1. Isolation: Isolation is essential to prevent contamination from foreign pollen. Spatial isolation is commonly practiced, requiring a minimum distance of 400 m for foundation seed and 200 m for certified seed production. Temporal isolation, where sowing dates are adjusted to avoid overlapping flowering periods, can also be employed.

2. Roguing: Roguing involves the systematic removal of off-type, diseased, and undesirable plants at different growth stages. It is carried out during vegetative, pre-flowering, flowering, and pre-harvest stages to maintain genetic purity.

3. Synchronization of Flowering: Synchronization between male and female parental lines is critical for effective pollination. This is achieved through staggered sowing, selection of appropriate parental lines, and agronomic adjustments.

4. Controlled Pollination: Ensuring that pollen from the desired male parent fertilizes the female parent is the cornerstone of hybrid seed production. This is achieved through detasselling or use of cytoplasmic male sterility systems.

5. Agro-Climatic Requirements: Maize requires a warm and moderately humid climate for optimal growth and seed production. Ideal temperature ranges from 20°C to 30°C. Excessive rainfall or high humidity during flowering can hinder pollen viability and silk receptivity, leading to poor seed set. Well-drained loamy soils rich in organic matter are most suitable for maize cultivation.

Land Selection and Field Preparation

Selection of appropriate land is crucial for maintaining seed quality. Fields should be free from volunteer plants and should not have been previously cultivated with maize of a different variety. Proper land preparation involves deep ploughing followed by harrowing and levelling to ensure a fine tilth. Crop rotation is recommended to minimize pest and disease incidence and maintain soil fertility.

Sowing Techniques and Planting Geometry

Proper sowing ensures uniform crop stand and efficient utilization of resources. Row spacing typically ranges from 60–75 cm, while plant spacing is maintained at 20–25 cm. In hybrid seed production, the ratio of male to female rows is critical and usually ranges from 1:2 to 1:4 depending on the hybrid type and pollen production capacity. Staggered sowing of male and female lines is often practiced to achieve synchronization of flowering, especially when parental lines differ in maturity duration (Tiwari et al. 2021).

Nutrient Management

Balanced fertilization is essential for vigorous plant growth and optimal seed yield. Nitrogen is applied in split doses to support vegetative growth and reproductive development. Phosphorus promotes root development and flowering, while potassium enhances stress tolerance and seed quality. Micronutrients such as zinc and boron may also be required in deficient soils.

Water Management

Irrigation plays a critical role in maize seed production, particularly during tasselling, silking, and grain filling stages. Water stress during these stages can severely reduce pollination efficiency and seed development. However, excessive irrigation should be avoided as it may lead to waterlogging and increased disease incidence.

Detasseling in Hybrid Seed Production

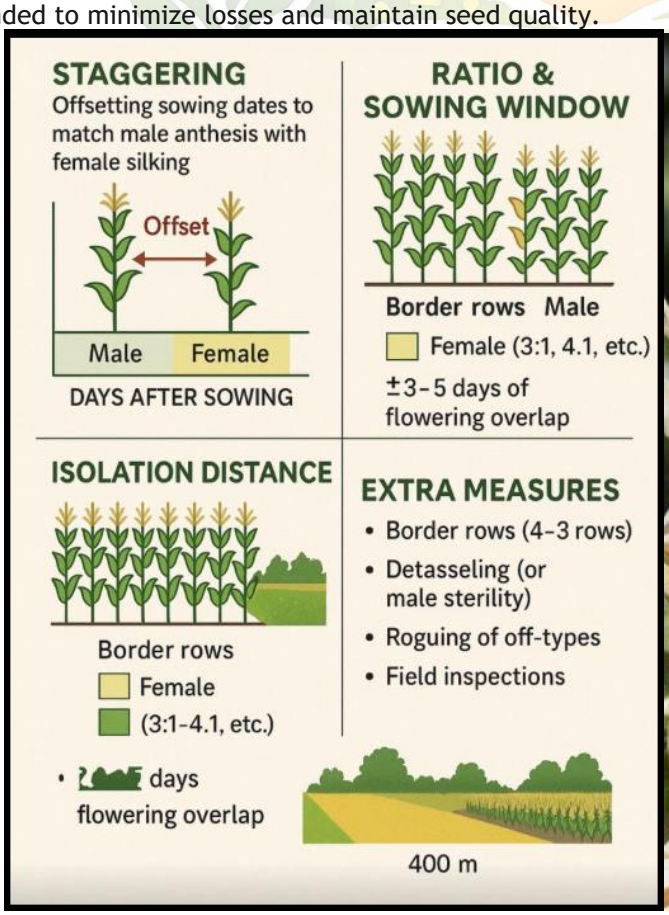
Detasselling is one of the most critical operations in hybrid maize seed production. It involves the removal of tassels from female plants before pollen shedding to prevent self-pollination. This ensures that fertilization occurs only from the designated male parent. Detasselling must be carried out meticulously and timely, as delayed or incomplete removal can lead to genetic contamination. The process is labour-intensive and requires skilled workers to maintain high accuracy levels. Mechanical detasselling is being explored to reduce labour costs and improve efficiency (MacRobert et al. 2014).

Pollination Dynamics and Seed Set

Maize is wind-pollinated, and successful pollination depends on adequate pollen production, favourable weather conditions, and proper synchronization of flowering. Each tassel can produce millions of pollen grains, but their viability is short-lived, typically lasting only a few hours under field conditions. Environmental stresses such as high temperature, low humidity, and drought can adversely affect pollen viability and silk receptivity, leading to poor kernel development. Therefore, maintaining optimal field conditions during flowering is essential for maximizing seed yield.

Crop Protection in Seed Production Fields

Seed production fields require rigorous pest and disease management to ensure seed health and quality. Major insect pests include stem borers, shoot flies, and armyworms, while important diseases include downy mildew, leaf blights, and rusts. Integrated pest management strategies combining cultural, biological, and chemical methods are recommended to minimize losses and maintain seed quality.





Harvesting and Post-Harvest Management

Harvesting should be carried out at physiological maturity when kernels attain maximum dry weight. At this stage, kernel moisture content is typically around 20–25%. Delayed harvesting may lead to field losses due to pests, diseases, or lodging. After harvest, cobs are dried to reduce moisture content to safe storage levels (12–13%). Shelling should be done carefully to avoid mechanical damage to seeds. Cleaning and grading are essential to remove inert matter and ensure uniform seed size. Proper storage under cool and dry conditions is necessary to maintain seed viability and vigour.



Seed Certification Standards and Quality Control

Seed certification ensures that seeds meet prescribed quality standards. It involves field inspections, seed testing, and verification of genetic purity. Parameters such as germination percentage, moisture content, and physical purity are evaluated. Strict limits are set for off-types and contaminants to ensure high-quality seed production (Tunwar and Singh 2015).

Challenges in Maize Seed Production

Maize seed production faces several challenges, including maintaining isolation in fragmented landholdings, labour-intensive detasseling operations, synchronization of flowering, and climatic uncertainties affecting pollination. Additionally, pest and disease pressures can compromise seed quality if not managed effectively.

Advances and Future Prospects

Recent advancements in maize seed production include the use of cytoplasmic male sterility (CMS) systems, which eliminate the need for manual detasseling, thereby reducing labor costs and improving efficiency. Molecular markers and genomic tools are being utilized to ensure genetic purity and accelerate breeding programs. Mechanization and precision agriculture technologies are also contributing to improved seed production efficiency and quality.

Conclusion

Seed production technology of maize is a complex and highly specialized process that requires a thorough understanding of crop biology, strict adherence to production principles, and meticulous management practices. The success of hybrid maize cultivation depends on the availability of high-quality seed with superior genetic purity and vigor. Adoption of advanced technologies, improved management practices, and robust certification systems will play a crucial role in meeting the growing demand for quality maize seed and ensuring sustainable agricultural productivity.

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Floral Microbiome: The Invisible Life in Flowers

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Dr. S. P. Mirunalini[1], Dr. A. Shanthi[1], Dr. M. Manikandan[1], Dr. C. Jayalakshmi[1]
[1]Department of Horticulture, Pandit Jawaharlal Nehru College of Agriculture & Research Institute, Karaikal – 609 603.

Flowers are admired for their beauty, colour and fragrance. They play an important role in nature by attracting pollinators such as bees, butterflies and birds. However, beyond their visible charm lies an invisible world of microscopic life. Every flower hosts a diverse community of microorganisms including bacteria, fungi and yeasts. This hidden microbial community associated with flowers is known as the **floral microbiome**.



The floral microbiome forms a tiny ecosystem on different parts of the flower such as petals, nectar, pollen and stigma. These microorganisms are not randomly present; instead, they interact with the plant and sometimes with visiting pollinators. The study of floral microbiomes has gained increasing attention in recent years as scientists recognize their role in shaping floral traits and plant-pollinator interactions.



How do Microbes Reach Flowers?

Flowers are constantly exposed to the environment, making them ideal landing sites for microbes. Microorganisms reach flowers through several pathways. Wind and air particles can carry microbial spores, while rainwater may deposit microbes onto floral surfaces. In addition, microbes may originate from other plant parts such as leaves and stems.

One of the most important routes of microbial transmission is through pollinators. When insects such as bees visit flowers to collect nectar and pollen, they inadvertently carry microorganisms on their bodies. As they move from one flower to another, these microbes are transferred and colonize new floral habitats. In this way, pollinators act as important vectors for spreading microbes among plants.

Microbes in Early Flower Development

Microorganisms can colonize flowers at very early stages of development. Even before anthesis, flower buds and nectar may contain detectable bacterial and fungal communities. Bacteria such as ***Acinetobacter*** have been reported from nectar and other floral tissues including pollen and stigma. Newly opened petals also harbour culturable microbial communities, indicating that flowers are seldom sterile.



Increase of Microbial Populations Over Time

The abundance of microbes generally increases as flowers age. Studies in plants such as ***Agave palmeri*** (Palmer's century plant) have shown that microbial populations are initially low before flower opening but increase significantly over time as flowers remain exposed to environmental factors and pollinator visits.



Influence of Pollinators on Floral Microbiomes

Pollinators can also shape floral microbial communities by transferring microbes between flowers. In hummingbird-pollinated plants such as *Diplacus aurantiacus* (Sticky monkey-flower) and *Epilobium canum* (California fuchsia), nectar bacteria are found more frequently in flowers visited by hummingbirds or large insects.

	
Diplacus aurantiacus	***Epilobium canum***

Floral Microbiome and Pollinator Behaviour

The microorganisms present in flowers can influence the behaviour of pollinators. Certain microbes produce volatile compounds that modify the natural scent of flowers. Pollinators such as bees are highly sensitive to these scent cues and may change their visiting patterns based on the altered fragrance. In some cases, microbial activity in nectar can even affect the taste and chemical composition of nectar, which further influences pollinator preference.



Types of Microbes Found in Flowers

A variety of microorganisms can inhabit flowers. These include bacteria that thrive on floral surfaces, yeasts that grow in nectar and fungi that may colonize petals or reproductive tissues. Some microbes originate from the surrounding environment, while others are specifically adapted to survive in the unique conditions present in flowers.

Nectar, for example, contains sugars and nutrients that support the growth of specialized yeast and bacterial species. These microbes have developed the ability to tolerate high sugar concentrations and other chemical compounds found in nectar. As a result, each flower may host a distinct microbial community depending on environmental conditions and pollinator activity.

Environmental Factors Affecting Floral Microbiomes

The composition of the floral microbiome can vary depending on environmental conditions. Factors such as temperature, humidity, rainfall, and surrounding vegetation can influence the types of microbes present in flowers.

In addition, the diversity of pollinators visiting flowers also plays an important role in shaping microbial communities. Flowers visited by many pollinators may host a richer microbial diversity compared to those with fewer visitors.

Influence of Microbes on Floral Traits

The presence of microbes in flowers can influence several important floral characteristics. One of the most fascinating effects is their ability to alter floral scent. Microorganisms can metabolize nectar components and produce their own volatile compounds, which may modify the natural fragrance emitted by flowers.

Floral scent plays a key role in attracting pollinators, and even small changes in scent composition can influence pollinator behaviour. Some microbes may enhance floral aroma, while others may reduce its intensity or produce new scent molecules. In addition to fragrance, microbes can also affect nectar chemistry by altering sugar composition and pH.

These microbial activities can indirectly influence how pollinators perceive and interact with flowers. As a result, the floral microbiome contributes to shaping plant–pollinator relationships in natural ecosystems.

Importance of Studying the Floral Microbiome

Understanding the floral microbiome has important implications for both ecology and agriculture. By studying microbial communities associated with flowers, scientists can gain insights into plant health, pollination biology and ecosystem dynamics.

In agriculture and horticulture, knowledge of floral microbiomes may help improve crop productivity and pollination efficiency. Certain beneficial microbes could potentially be used to protect flowers from harmful pathogens or to enhance floral quality in ornamental plants.

The study of floral microbiomes also opens new avenues for research in plant–microbe interactions and sustainable crop management. As scientists continue to explore this hidden microbial world, they are discovering that flowers are not just beautiful structures but also complex habitats supporting diverse life forms.

A New Perspective on Flowers

Traditionally, flowers have been studied mainly for their role in reproduction and pollination. However, the discovery of floral microbiomes has revealed that flowers function as dynamic microhabitats where plants, microbes and pollinators interact.

Recognizing this hidden dimension of floral biology encourages us to appreciate flowers in a new way. Behind every fragrant bloom lies an unseen community of microorganisms that quietly influences plant health, fragrance and ecological interactions. The floral microbiome therefore represents an exciting frontier in plant science, reminding us that even the most delicate flowers host a fascinating microbial world.

Floral Microbiome and Plant Health

The microbial community associated with flowers may also contribute to plant health. Some beneficial microbes can protect flowers from harmful pathogens by competing for nutrients and space. This natural microbial competition can reduce the chances of disease development in floral tissues and reproductive organs.



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Beyond the Bin: Redesigning Our World for a Circular Economy

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Dr. Ch. Sneha Latha[1], Dr. Swetha Kodali[2]

[1]Assistant Professor, Department of Resource Management and Consumer Sciences, College of Community Science, PJTAU, Saifabad, Hyderabad, Telangana, India -500004.

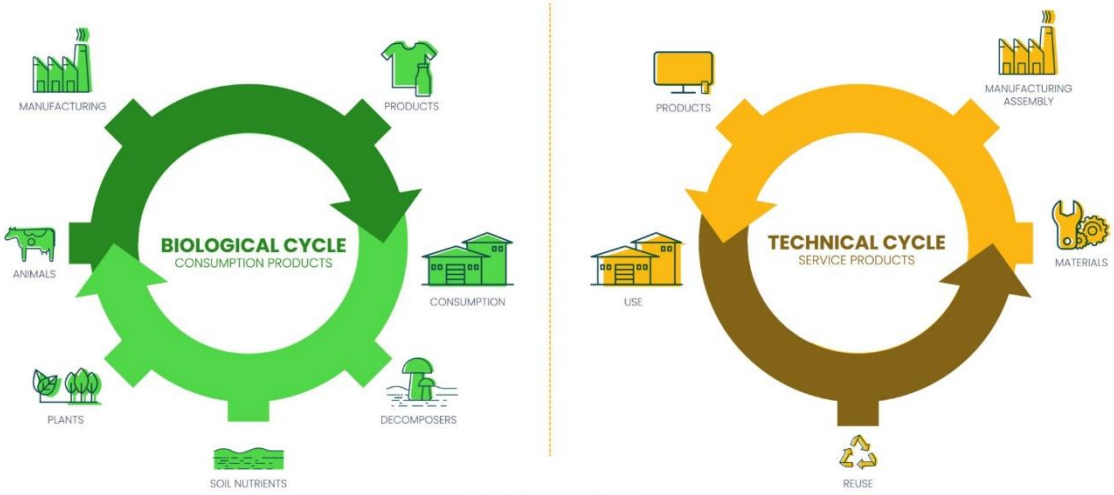
[2]Scientist, Family Resource Management, All India Coordinated Research Project on Women in Agriculture, PG&RC, Professor Jayashankar Telangana Agricultural University, Rajendranagar, Hyderabad, Telangana, India - 500 030.

We have all seen the images: mountains of plastic in landfills and "islands" of waste swirling in our oceans. For decades, our global economy has operated on a linear model—we take resources from the earth, make products, and then dispose of them.

But as the environmental toll of single-use plastics becomes impossible to ignore, a more elegant and sustainable solution is gaining momentum: the Circular Economy. This isn't just about better recycling; it's about a fundamental redesign of how we produce, consume, and value everything in our lives.

What is the Circular Economy?

At its heart, a circular economy mimics nature. In an ecosystem, there is no such thing as "waste." The "outputs" of one process become the "inputs" for another.



THE DIFFERENCE BETWEEN
RECYCLING AND CIRCULAR ECONOMY

While the linear model follows a "take-make-waste" path, the circular model is built on three main pillars:

1. **Eliminate waste and pollution:** Designing products so that waste isn't created in the first place.
2. **Circulate products and materials:** Keeping materials in use—at their highest value—for as long as possible.
3. **Regenerate nature:** Moving from a "protection" mindset to one that actively improves the environment.

Redesigning Materials: Beyond the "Plastic Band-Aid"

Replacing a plastic straw with a paper one is a start, but it doesn't solve the systemic issue. To move beyond single-use plastics, we are seeing a revolution in material science:

1. Bio-benign Materials: Scientists are developing packaging made from mushroom mycelium, seaweed, and agricultural waste. These don't just "break down"—they provide nutrients to the soil.

2. High-Performance Polymers: For products that require durability, engineers are creating plastics designed for "infinite" chemical recycling, allowing them to be broken down to a molecular level and rebuilt without losing quality.

3. The Rise of "Permanent" Materials: Aluminium and glass are becoming the stars of the circular world because they can be recycled indefinitely without degrading.

Redesigning Systems: Products as a Service

The most radical shift in the circular economy isn't the material—it's the business model. Why do we need to *own* a drill when we only need the *hole*?

The "Product-as-a-Service" (PaaS) Model

In a circular system, companies often retain ownership of their products. This incentivizes them to build things that last, are easy to repair, and are simple to disassemble.

1. Example: Instead of buying lightbulbs, a company might pay for "lighting hours." The manufacturer (like Philips) remains responsible for the hardware, ensuring it is energy-efficient and recyclable.

2. Example: Clothing subscription and repair services that ensure a garment is worn 100 times instead of five before being fiber-recycled.

The Path Forward: Challenges and Hope

Transitioning to a circular economy isn't without hurdles. It requires global policy shifts, such as Extended Producer Responsibility (EPR) laws, and a massive investment in infrastructure for collection and processing.

However, the benefits are clear. Beyond saving the planet, a circular economy is estimated to provide trillions of dollars in economic growth by 2030. It creates local jobs in repair and remanufacturing and builds more resilient supply chains.

The goal is no longer just to "do less harm." It is to design a world where our very existence helps the planet thrive. By moving beyond the era of disposability, we aren't just cleaning up the trash—we're building a future that's designed to last.

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Moringa: A Miracle Tree for Nutritional Security and Farmer Income

Article ID: 73504

Dr. Nile Shubhangi Gorakhnath[1], Er. Dhawale Shubham Namdev[2]
[1]PhD, ICAR-Indian Agricultural Research Institute, New Delhi.
[2]PhD, Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola, MH.

Abstract
Moringa (*Moringa oleifera*), popularly known as drumstick, is a highly nutritious and fast-growing tree widely cultivated in India. It is often referred to as a "miracle tree" due to its exceptional nutritional composition and multiple uses in food, medicine, and agriculture. Moringa plays a crucial role in combating malnutrition while also providing sustainable income opportunities for farmers. Its adaptability to diverse agro-climatic conditions, low input requirements, and high market demand make it an ideal crop for enhancing both nutritional security and rural livelihoods. This article discusses the importance of moringa, improved cultivation practices, processing, and its role in income generation.

Keywords: Moringa, Nutritional Security, Farmer Income, Value Addition, Functional Foods, Sustainable Agriculture.

Introduction
India is one of the leading producers of moringa, with major cultivation in Tamil Nadu, Andhra Pradesh, Karnataka, and Maharashtra. In recent years, moringa has gained global recognition as a superfood due to its high nutritional value and medicinal properties. The tree is drought-tolerant, grows well in poor soils, and requires minimal care, making it highly suitable for small and marginal farmers. Moringa is not only a horticultural crop but also a powerful solution for addressing malnutrition and promoting sustainable agriculture.

Nutritional Significance of Moringa



Moringa leaves are considered one of the most nutrient-dense plant foods. They are rich in essential nutrients required for human health.

Key Nutritional Components

1. Protein: 20–30% (dry basis)
2. Vitamins: A, C, and E
3. Minerals: Calcium, iron, potassium
4. Antioxidants: Flavonoids and phenolic compounds

Regular consumption of moringa helps improve immunity, prevent anemia, and support overall health, especially among children, pregnant women, and lactating mothers.

Role in Nutritional Security

Malnutrition remains a major concern in India, particularly in rural and tribal regions. Moringa offers a practical and affordable solution:

1. Easily grown in kitchen gardens and small farms
2. Provides a continuous supply of fresh leaves
3. Can be processed into powder for year-round use
4. Suitable for inclusion in mid-day meal schemes and nutrition programs

Incorporating moringa into daily diets through traditional recipes, soups, and fortified foods can significantly enhance nutritional intake.

Cultivation Practices for Higher Productivity

Climate and Soil: Moringa thrives in tropical and subtropical climates and grows well in well-drained sandy or loamy soils (pH 6.0–7.5).

Propagation:

a. Through seeds or stem cuttings
b. Direct sowing or nursery raising

Spacing:

a. Intensive system: 1.5 × 1.5 m
b. Perennial system: 3 × 3 m

Nutrient Management: Application of organic manure and balanced fertilizers improves yield and quality.

Irrigation: Though drought-tolerant, periodic irrigation enhances growth and productivity.

Harvesting:

a. Leaves: 60–90 days after planting
b. Pods: harvested when tender and green

Processing and Value Addition

Processing moringa into value-added products enhances shelf life and marketability.

Processing steps:

a. Harvesting fresh leaves
b. Cleaning and washing
c. Drying (shade, solar, or mechanical drying)
d. Grinding into powder
e. Packaging in airtight containers

Value-added products include:

a. Moringa leaf powder
b. Nutraceutical capsules
c. Herbal tea and beverages
d. Fortified bakery products

Income Generation and Market Potential

Moringa provides multiple income opportunities:

1. **Fresh Market Sales:** Leaves and pods sold in local markets
2. **Value-Added Products:** Powder, supplements, and processed foods
3. **Export Potential:** Growing international demand for moringa powder and oil

Economic Benefits

1. Low cultivation cost
2. High yield and profitability
3. Year-round income generation

Farmers can increase profitability through processing, branding, and direct marketing.

Entrepreneurship Opportunities

Moringa-based enterprises offer excellent scope for rural development and women's empowerment.

Opportunities include:

a. Small-scale powder production units
b. Herbal and nutraceutical product manufacturing
c. Development of functional foods
d. Online and local market sales

Self-help groups (SHGs) and farmer-producer organizations (FPOs) can play a key role in scaling these ventures.

Challenges and Constraints

1. Limited awareness among farmers
2. Lack of processing infrastructure
3. Poor post-harvest management
4. Market price fluctuations

Addressing these issues through training, extension services, and policy support is essential.

Future Prospects

The global demand for functional foods and natural health products is increasing rapidly. Moringa has immense potential in this sector. Research on improved varieties, efficient processing techniques, and product development will further enhance its scope.

Conclusion

Moringa is rightly called a “miracle tree” due to its exceptional nutritional and economic benefits. It serves as a sustainable solution for improving nutritional security while providing a reliable source of income for farmers. With proper cultivation, processing, and market linkage, moringa can play a transformative role in Indian agriculture and rural livelihoods.

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3D Food Printing: The Future of Customized Cuisine on Your Plate

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Karishma Verma[1]
[1]Ph.D Scholar, Dr. PDKV, Akola, Maharashtra.

Abstract

3D Food Printing (3DFP) represents a transformative shift in the modern culinary landscape by merging digital precision with nutritional science. This innovative technology uses additive manufacturing to create edible objects layer-by-layer through a specific three-step workflow: digital design, slicing into G-code, and fabrication. By extruding "edible inks" like purees, doughs, and lab-grown meats, printers produce intricate geometries that traditional cooking methods cannot achieve. The primary applications of 3DFP focus on personalized nutrition by tailoring meals to individual medical data and dietary restrictions. In healthcare, this technology creates visually appealing, texture-modified diets for patients with dysphagia to improve both dignity and nutrition. Furthermore, 3DFP supports global sustainability by reducing food waste through on-demand production and making alternative proteins, such as insects and algae, more palatable for consumers. Strategic environments like the military and space agencies also utilize these space-efficient, nutritionally stable meal solutions. Current research is pushing boundaries into 4D, 5D, and 6D printing, where food changes shape, color, or flavor in response to external stimuli like heat. Despite these clear benefits, 3DFP faces significant hurdles, including slow printing speeds, unpredictable material behavior under pressure, and consumer hesitation regarding machine-cooked meals. However, by eliminating specialized molds and supporting decentralized production, the technology is moving rapidly from research labs to industrial and home applications. Ultimately, 3D food printing proves that the future of nutrition lies in how we design our food as much as what we actually consume.

Introduction

Imagine a kitchen where the usual clutter of mixing bowls and preheated ovens is replaced by the quiet hum of a digital architect. Instead of following a traditional recipe, you select a file on a screen and watch as a personalized chocolate cake is meticulously built, layer by layer, from the bottom up. In just a few minutes, you're presented with a dessert that is a precision and engineered meal. A meal of exact protein-to-carb ratio for an intense training day and a specific, soft texture for th person, who struggles to swallow traditional food.

This is the frontier of 3D food printing, a space where the creativity of a chef meets the precision of a high-tech lab. By using specialized design software and "edible inks, this technology turns digital blueprints into real, edible art. We're talking about intricate geometries and internal textures that even the most talented human hands couldn't possibly sculpt or bake using old-school methods. The big idea here is a future of food that is sustainable. By printing only what we need, right when we need it, we can drastically cut down on the massive waste created by traditional food manufacturing. It also gives us clever way to eat more sustainably, turning eco-friendly ingredients like algae into shapes and flavors we actually want to eat. But, there are still some things to work on. Right now, printing is a slow process, and food is a lot more temperamental to work with than plastic or metal. From high-end research facilities to experimental kitchens, we are witnessing a fundamental shift in how we conceive, create, and enjoy the food on our plates.

What is 3D Food Printing?

3D Food Printing (3DFP) sometimes called additive manufacturing. It is the process of turning a digital blueprint into a physical, edible object. Instead of using a knife or mold, a printer builds your meal layer by layer, following a computer's instructions with robotic precision. This allows us to create intricate shapes and internal structures, like a hollow chocolate sphere or a geometrically perfect cracker, that simply couldn't be made by hand or with traditional kitchen tools. The journey from a digital idea to a physical plate follows a simple, three-step workflow (Derossi et al., 2024).

First, there is the **Digital Design**, where a model is created using specialized software. Next comes **Slicing**, where that 3D model is broken down into hundreds of thin, 2D layers; this creates a set of instructions called "G-code" that tells the printer exactly how to move and how much food to "extrude." Finally, there is **Fabrication**, where the machine follows those coordinates to stack the "edible ink" until the food item is complete. These "inks" are real food materials like chocolate, vegetable purees, doughs, or even lab-grown meats, usually prepared as a smooth paste or gel. While there are several high-tech ways to do this, about 95% of the time, we use extrusion-based systems.

Current Application and Innovation

Current application of 3D food printing is transforming the global culinary landscape today. This innovative technology moves beyond simple artistic shapes to solve complex nutritional, medical, and environmental challenges (Prithviraj et al., 2025).

1. Healthcare and Personalized Nutrition: Personalized nutrition is a primary goal for this emerging field. A 3D printer can dose specific macro- and micronutrients into a meal based on your individual medical data or dietary requirements (Zhu et al., 2023).

a. Geriatric and Dysphagia Care: These machines create texture-modified diets for patients with swallowing difficulties. The printers produce safe, soft meals that mimic the appearance of traditional foods to improve a patient's appetite and dignity.

b. Targeted Supplements: Companies like Nourished already use 3D printing to produce customized multivitamin gummies. These snacks match the specific nutritional profile of each individual customer.

c. Functional Foods: Researchers print specialized structures like mashed potatoes or cereal snacks infused with probiotics. This design protects live bacteria during consumption so they can benefit the digestive system.

2. Strategic and Extreme Environments: 3D food printing works exceptionally well in places with limited resources. It is a perfect tool for soldiers and astronauts in high-pressure situations.

a. Military Applications: The military prints individualized rations for soldiers based on their real-time energy expenditures on the battlefield. This technology also extends the shelf life of food components by keeping ingredients separate until the moment of printing.

b. Space Exploration: NASA uses 3D food printing to provide nutritionally stable and tasty meals for long-duration missions. These compact machines save valuable storage space on the spacecraft while offering variety to the crew.

3. Alternative Proteins and Sustainability: Scientists use this technology to support global food security and environmental sustainability. It helps people incorporate unconventional or "unappealing" protein sources into a standard human diet.

a. Alternative Meats: Engineers print realistic "steaks" using plant-based proteins like soy or pea. They also use bovine stem cells to grow real meat tissues inside a laboratory environment.

b. Cheese Alternatives: This technology creates plant-based cheese analogues for people with dietary restrictions. It provides customized dairy solutions for individuals with lactose intolerance.

c. Waste Reduction: Printers upcycle food industry by-products like potato processing waste or fruit peels into nutritious snacks. This process turns potential trash into value-added food products for the market.

Technological and Sensory Innovations

Current research is pushing the boundaries of traditional printing into more dynamic and responsive realms. 4D food printing adds the element of time as a fourth dimension to your plate. These printed objects undergo dynamic changes in shape, color, or flavor when you expose them to external stimuli like microwave heating or pH changes. Furthermore, 5D and 6D printing use multiple rotational axes and smart materials to create even more complex, responsive structures. Scientists also use coaxial printing to encapsulate bioactive compounds like curcumin or anthocyanins inside food. This method protects sensitive nutrients from degradation and controls their release inside the human body. In the world of cellular agriculture, 3D printers build edible "scaffolds" to help muscle and fat cells grow into realistic meat textures. While the market currently features a limited number of products like personalized pasta or intricate chocolates, these machines are rapidly advancing toward industrial-scale applications and everyday home use.

Challenges and Limitations

3D food printing (3DFP) is an exciting and emerging technology that brings together nutrition, science, and creativity. It offers a wide range of benefits from improving individual health to supporting sustainability and making food production more efficient (Singh and *Singh*, 2022).

1. Personalized Nutrition and Health: Personalized nutrition is a major advantage of 3D food printing (3DFP), as it allows meals to be tailored to individual health conditions, age, and dietary needs. The technology enables precise control of nutrients, including vitamins and minerals, according to medical requirements. It also allows the incorporation of functional ingredients like probiotics to improve immunity. Additionally, 3DFP supports disease management by designing foods that promote satiety and help control conditions such as obesity. Furthermore, it can reduce sugar and salt content using sensory techniques without affecting taste.

2. Specialized Applications (Healthcare, Military, and Space): 3D food printing (3DFP) is particularly useful for individuals with special dietary needs and in extreme environments. In healthcare, especially for dysphagia patients, it enables the preparation of soft, texture-modified foods that resemble real meals, improving acceptability and preventing malnutrition. In addition, the technology is valuable in military and space applications, where it can produce meals on demand under challenging conditions. It allows the creation of customized rations for soldiers and provides compact, safe, and nutritious food options for astronauts during long-duration missions.

3. Sustainability and Environmental Impact: 3D food printing (3DFP) also plays an important role in promoting a sustainable food system. It helps reduce food waste by producing food only when needed and by utilizing by-products such as vegetable peels and broken grains to create value-added products. In addition, the technology supports the use

of alternative protein sources like insects, algae, and lab-grown meat by converting them into familiar and acceptable forms. Furthermore, advanced concepts such as 4D printing enable efficient transportation, as food can be stored in compact forms and later transformed into its final structure during cooking, saving space and resources.

4. Culinary Innovation and Consumer Experience: 3D food printing (3DFP) opens up new possibilities in food design and creativity. It enables the creation of unique and complex shapes that are not achievable through traditional cooking methods. In addition, it allows a customized food experience, where individuals can personalize taste, texture, and appearance according to their preferences. Furthermore, it encourages consumer involvement in food design, which increases enjoyment and acceptance; this concept, known as the "IKEA effect," can be particularly useful in promoting healthier eating habits among children.

5. Economic and Production Benefits: 3D food printing (3DFP) is both cost-effective and flexible. It eliminates the need for molds or specialized tools, reducing production costs while allowing easy customization. Additionally, it supports decentralized production, enabling food to be prepared closer to the point of consumption, which reduces transportation costs and improves freshness. Overall, 3DFP is a powerful technology that enhances food production and consumption while promoting better health, sustainability, and innovation in the food industry.

Conclusion

3D food printing is a powerful technology that merges nutrition, science, and creativity to revolutionize the food industry today. This innovation shifts our focus toward precision-engineered meals that support individual well-being through personalized nutrient control and specialized healthcare diets. The process also promotes global sustainability by reducing waste through on-demand production and making eco-friendly proteins more appetizing for the average consumer. While hurdles like slow speeds and material unpredictability remain, the technology is rapidly moving from research labs into our homes and factories. Ultimately, 3D food printing proves that the future of food depends on how we design our meals rather than just what we eat.

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Quick-Growing Spinach Varieties for Intensive Farming

Article ID: 73506

Dr. M. Kabilan[1]
[1]Regional Coffee Research Station, Coffee Board, Thandigudi, Tamil Nadu, India.

Introduction

Spinach (*Spinacia oleracea* L.), commonly known as palak, is a highly nutritious leafy vegetable widely cultivated across the world. It is rich in iron, calcium, vitamins A, C and K and antioxidants, making it an essential component of a balanced diet. Due to its short growth duration, high biomass production and multiple harvest potential, spinach is particularly suitable for intensive farming systems. Intensive farming focuses on maximizing productivity per unit area through high-density planting, efficient nutrient management and rapid crop turnover. In this context, the selection of quick-growing spinach varieties plays a crucial role in achieving higher yields and ensuring continuous production. Fast-growing spinach varieties can be harvested within 20–40 days, making them ideal for multiple cropping cycles and year-round cultivation.



Importance of Quick-Growing Varieties in Intensive Farming

Quick-growing spinach varieties are essential for intensive farming systems because they enable rapid crop turnover, efficient land use and increased profitability. These varieties allow farmers to harvest multiple crops within a short period, ensuring a steady supply of fresh produce to the market. Early maturity also reduces exposure to pests, diseases and adverse climatic conditions. Additionally, fast-growing varieties are ideal for urban agriculture, hydroponics and protected cultivation systems, where space and time are critical factors.

Characteristics of Quick-Growing Spinach Varieties

Quick-growing spinach varieties possess specific traits that make them suitable for intensive cultivation. These include rapid germination, early maturity, high leaf production and tolerance to bolting. Such varieties typically produce tender, succulent leaves that are suitable for both fresh consumption and processing. They also exhibit good regrowth क्षमता, allowing multiple cuttings from a single planting. High nutrient-use efficiency and adaptability to different growing conditions further enhance their suitability for intensive farming.

Popular Quick-Growing Spinach Varieties

Several spinach varieties have been identified for their rapid growth and high productivity. Varieties such as ‘Space’, ‘Tyee’ and ‘Bloomsdale’ are known for their fast growth, disease resistance and adaptability. ‘Space’ is a smooth-leaf variety that matures quickly and resists bolting, making it suitable for successive planting. ‘Tyee’ is a fast-growing savoy type with thick, dark green leaves and resistance to downy mildew, maturing in about 39 days. ‘Bloomsdale’, an heirloom variety, is widely grown due to its high yield and good flavor, although slightly longer in duration.

In the Indian context, varieties such as Pusa Palak, All Green, Jobner Green and hybrids like Swarna and Palak Hybrid F1 are popular for their rapid growth and high yield potential. Swarna, for instance, can be harvested within 30–35 days and supports multiple cuttings, making it ideal for intensive production systems. Similarly, Giant Palak varieties can be harvested as early as 20–25 days after sowing, allowing multiple harvests.

Growth Duration and Harvesting Efficiency

One of the key advantages of quick-growing spinach varieties is their short growth cycle. Baby spinach leaves can be harvested within 20–30 days, while mature leaves are ready within 35–50 days depending on the variety. This rapid

growth allows farmers to practice sequential cropping, ensuring continuous production throughout the year. Frequent harvesting of outer leaves encourages regrowth and increases total yield per unit area.

Suitability for Intensive and Protected Cultivation

Quick-growing spinach varieties are highly suitable for intensive farming systems, including protected cultivation and hydroponics. Their rapid growth and compact plant structure make them ideal for high-density planting. In hydroponic systems, varieties such as Bloomsdale and Monnopa perform well due to their adaptability and uniform growth. Vertical farming systems further enhance productivity by utilizing space efficiently and enabling year-round cultivation.



Nutrient and Water Management for Rapid Growth

Efficient nutrient and water management is essential for maximizing the performance of quick-growing spinach varieties. Spinach requires a balanced supply of nitrogen for leaf development, along with phosphorus and potassium for overall growth. Organic manures and biofertilizers improve soil fertility and enhance nutrient uptake. Frequent but light irrigation ensures consistent soil moisture, which is critical for rapid growth and tender leaf production. Drip irrigation systems are particularly effective in maintaining optimal moisture levels and reducing water wastage.

Role in Multiple Cropping Systems

Quick-growing spinach varieties are ideal for inclusion in multiple cropping and intercropping systems. They can be grown as a short-duration crop between main crops, maximizing land utilization and income. Their rapid growth and early harvest make them suitable for crop rotation systems, improving soil health and reducing pest and disease cycles.

Pest, Disease and Bolting Management

Although quick-growing varieties have a shorter exposure period to pests and diseases, proper management is still necessary to ensure high productivity. Integrated pest management practices, including the use of resistant varieties, biological control agents and minimal pesticide application, are recommended. Bolting, which is influenced by temperature and photoperiod, can be minimized by selecting bolt-resistant varieties such as Space and Tyee. Maintaining optimal growing conditions and timely harvesting also helps prevent bolting.

Economic Benefits of Quick-Growing Varieties

The adoption of quick-growing spinach varieties significantly enhances profitability by increasing cropping intensity and reducing production costs. Multiple harvests from a single planting and rapid crop cycles lead to higher returns per unit area. These varieties are particularly beneficial for small and marginal farmers, urban growers and commercial vegetable producers aiming to maximize productivity.

Constraints and Challenges

Despite their advantages, the cultivation of quick-growing spinach varieties faces challenges such as nutrient depletion due to intensive cropping, susceptibility to bolting under high temperatures and the need for efficient water management. Market fluctuations and post-harvest losses also affect profitability. Addressing these challenges requires improved management practices and technological interventions.

Future Prospects

The future of spinach cultivation lies in the development of improved varieties with enhanced growth rates, disease resistance and stress tolerance. Advances in breeding, biotechnology and precision agriculture will further enhance the

performance of quick-growing varieties. The integration of hydroponics, vertical farming and smart irrigation systems will play a crucial role in sustainable spinach production.

Conclusion

Quick-growing spinach varieties are a cornerstone of intensive farming systems, offering rapid growth, high productivity and multiple harvest potential. Their short growth cycle allows efficient land use, continuous production and increased profitability. By adopting improved varieties and integrating advanced cultivation practices, farmers can significantly enhance spinach yield and quality. With growing demand for nutritious leafy vegetables and increasing emphasis on sustainable agriculture, quick-growing spinach varieties will play a vital role in modern farming systems.

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History of Aquaculture: An Overview

Article ID: 73507

Prem Kumar[1], Safal Shandilya[1], Kedar Nath Mohanta[1]
[1]ICAR-Central Institute of Fisheries Education, Panch Marg, Off Yari Road, Versova, Andheri (W), Mumbai-400061.

Fish was naturally known to reside in rivers and lakes. It was eaten as food by humans living in earlier civilisations (Rabanal, 1998), as a protein source which they hunt down by spears and axes. It was known to be available as a natural food source to complete their nutritional and energy requirements.

India (3000 B.C. - 1889 A.D.)

Hora (1956) reported the occurrence of fish in India dated back to 3 millennium B.C. (3000-2001 B.C.). Nath (1966) provided the details about fish remains with cut marks were found from excavations of Harappa and Mohenjodaro (2600 B.C. – 1900 B.C) of the Indian Valley Civilisation (3300 – 1300 B.C.). Evidences of copper fish hooks from Lothal (Rao 1985) and painted pottery from Harappa depicting motifs of fish and man holding fishing nets from Harappa were found, both shown in Fig. 1 (Vats, 1940). From Kanmer, a prominent harappan site in Gujarat, archaeological evidences of pectoral spines of *Mystus sps.* and preoperculum, dentary and clethra of *Lates calcarifer* were found, both shown in Fig. 2 (Abhayan et al., 2020). In Indian sub-continent, fish culture practices was described in Kautliya's *Arthashastra* (370-283 B.C.) and further, for the period of 321-300 B.C., the first description about the use of reservoirs to hold the fish was first described (Rabanal, 1998). King Somesvara, the son of King Vikramaditya VI, composed the book, *Manasoltara*, in 1127 A.D., recorded common sport fishes of India (Hora, 1951) and it further described methods for fattening of fish in reservoirs. Bloch, whose commendable work *Auslandiche Fische* was published in 1785 A.D. (Bayly, 2025); in India, it was a significant event in the field of ichthyology. In 1822, Hamilton came up with his pioneer work *Fishes of Ganga* (Jhingran, 1982) which includes detailed description and illustrations of various fish species found in the region and it is recognised as a pioneering effortin Indian ichthyology. Jhingran (1982) pointed out the two epoch making contribution by Francis Day entitled *Fishes of India* and *Fauna of British India including Ceylon and Burma* (1878-1889), Day's work remains a cornerstone in the study of ichthyology and the understanding of India's aquatic ecosystems.

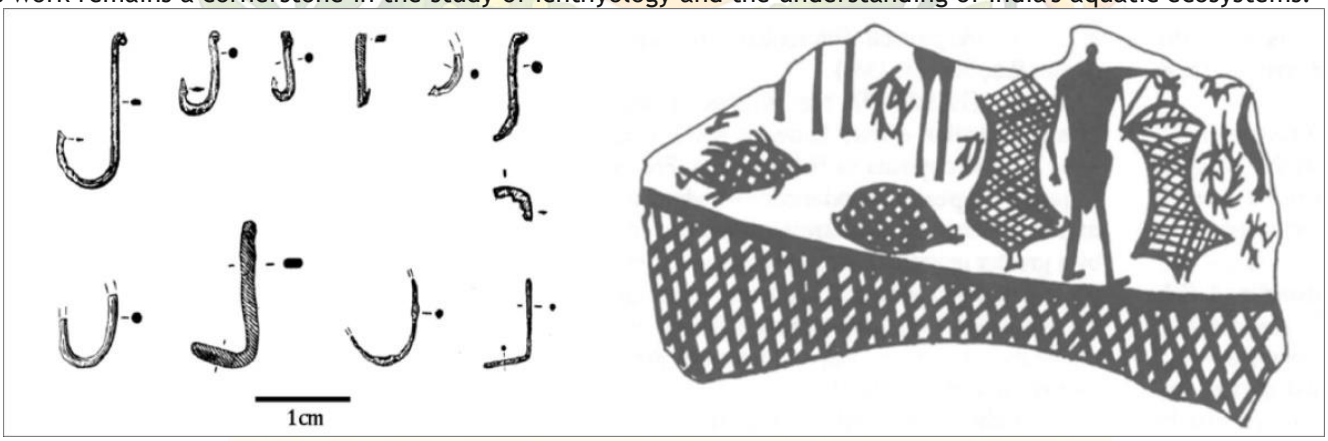


Fig. 1 (a) Copper fish hooks from Lothal (Rao 1985); (b) Painted pottery from Harappa depicting motifs of fish and man holding fish nets (Vats 1940).

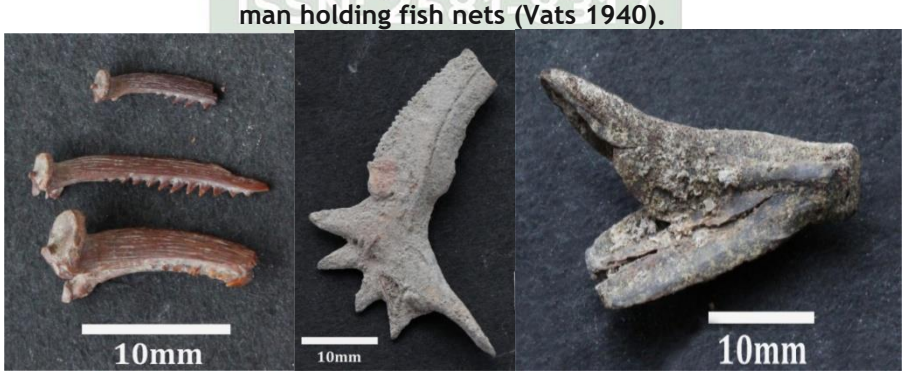




Fig. 2 a) Pectoral spines of *Mystus* sps. from Kanmer (Gujarat); b) Preoperculum of *Lates calcarifer* from Kanmer; c) Dentary of *Lates calcarifer* from Kanmer; d) Clethra of *Lates calcarifer* from Kanmer (Abhayan et al., 2020).

Egypt (2357-1768 B.C.)

Egyptians developed some form of aquaculture as the Chinese. Egyptian hieroglyphics showed evidence of pond culture from 2357 and 1786 BC (Jessé & Casey, 2008). The Tomb of Thebaine (Egyptian noble man) depicted in Fig. 3 in which the tilapia being cultured in artificial pond (Chimits, 1957).



Fig. 3. Tomb of Thebaine (Egyptian noble man) depicted in which the tilapia being cultured in artificial pond.

China (2000 B.C. – 1911 A.D.)

2000-1000 B.C.: Aquaculture has a long history dating as far as 4000 years ago i.e. 2nd century B.C. In China, aquaculture as husbandry developed overtime and the cradle of beginning of aquaculture by utilizing mainly the common carp (*Cyprinus carpio*) (Rabanal, 1998).

500 B.C. (473 B.C. or 475 B.C.): It was a great time with regards to annals of the history of aquaculture. Fan Lai wrote book entitled "*The Classic of Fish Culture*" (an earliest monograph of fish culture, evidence shown in Fig. 2 depicting Facsimile from the book of Fan Lai (https://www.fao.org/4/ag158e/AG158E04.html), it was first to incorporate record and describe the structure of ponds, the method of propagation of the common carp and the growth of fry (Vatsos, 2015).

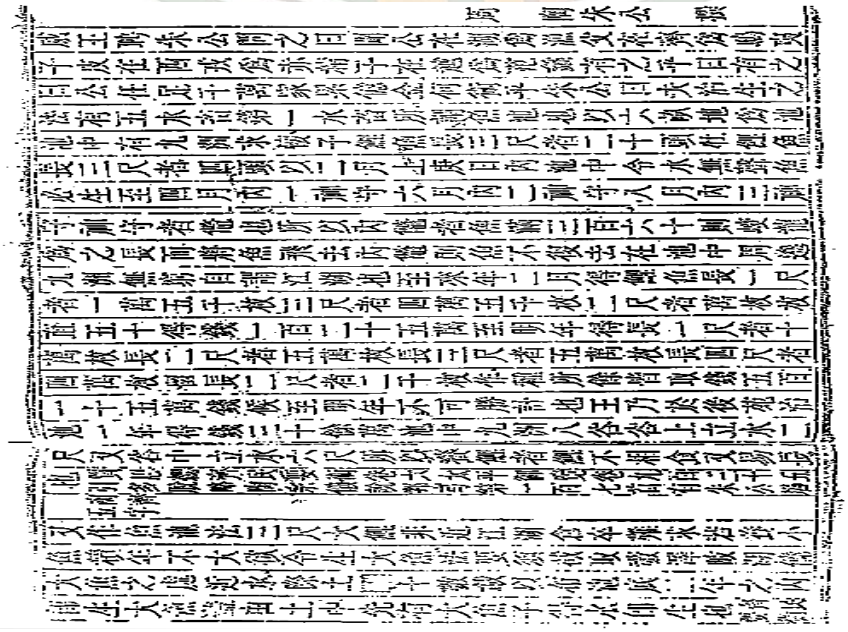


Fig. 4 Facsimile from the book of Fan Lai (https://www.fao.org/4/ag158e/AG158E04.html**)**

500 B.C. - 500 A.D.: This period was considered to be golden age of common carp culture in China and around its neighbours.

Tang Dynasty of China (618 A.D.-906 A.D.)

Tang emperor in China prohibited the culture of common carp, which became a blessing in disguise. It leads to the search for culture of other species such as silver carp (*Hypophthalmichthys molitrix*), grass carp (*Ctenopharyngodon idella*), big-head carp (*Hypophthalmichthys nobilis*) and mud carp (*Cirrhinus molitorella*) in polyculture which also resulted in maximizing the productivity of freshwater pond culture (Edwards, 2025).

1. Sung Dynasty (906 A.D. – 1120 A.D.): During time period systematic fry collection and dispersal in natural waters was highly developed. In around, 1243 A.D. evidence of transporting of fry in bamboo baskets was found and developed.

2. Ming Dynasty (1368 A.D. – 1644 A.D.): In this period, complete aquaculture processes were briefly detailed and described such as methods for culturing fry to adult, polyculture, the structure of ponds, rearing density, stocking/catching rotation, application of food and fertilizer and disease control methods. In China around 1639, the pond fish culture was incorporated in "Complete book of Agriculture".

3. Ching Dynasty (1644 A.D. – 1911 A.D.): During this period, emphasis was given on fry production, season of occurrence of fry, differentiation and separation of fry and their transport.

Other Parts of the World

Indonesia: Brackish water aquaculture flourished in early 15th century and spread to neighbouring countries like Philippines, Malaysia, Thailand and Taiwan (Ling, 1977).

Cambodia (Kampuchea): Chinese migration resulted in development cage culture of siluroids and related species in Mekong river about 200 years ago (Pillay & Kutty 2005).

Europe: Water areas were included in monasteries, temples and palaces of the ruler. Initially, in these places it started with holding of fish and later on culturing of fish. Species cultured were common carp (*Cyprinus carpio*) (Hickling, 1968).

North America: In 19th century, development of sport fishing by establishing hatcheries for their seed production and also for fulfilling the demand of food species of finfish, oysters, clams etc. (Brice et. al., 1900).

Africa: European people introduced aquaculture in Africa. During rainy season, the presence of extensive flood plains provided better environment for better for growth and reproduction of indigenous species. Further during dry seasons, concentrating them in marshes or depressions was seen. Common species cultured here are catfish, tilapia and common carp (Rabanal, 1998).

Australia and New Zealand: Trout and other cold water species, molluscs, oysters and mussel culture are being developed (Costa-Pierce, 2022).

Japan and Korea: China had an influence on these countries with respect to goldfish and carp culture. But, Japan introduced "closed door policy" which resulted in culture of finfishes, crustaceans, molluscs and other vertebrates and also invertebrates of high economic importance and enormous trade value. Development of highly efficient culture technologies is also characteristics of Japanese and Korean aquaculture (Rabanal, 1998).

Conclusion

After studying and analysing the available literature, we came to an opinion that Harappan Civilisation (Indus Valley Civilisation) i.e. Indian-subcontinent was credited to culture fish well before any other civilisation. Furthermore, Chinese and Egyptian civilisation flourished simultaneously in different parts of world. Chinese are well known for spreading fish culture in different parts of the world, similarly the Europeans are credited to spread fish culture in African continent.

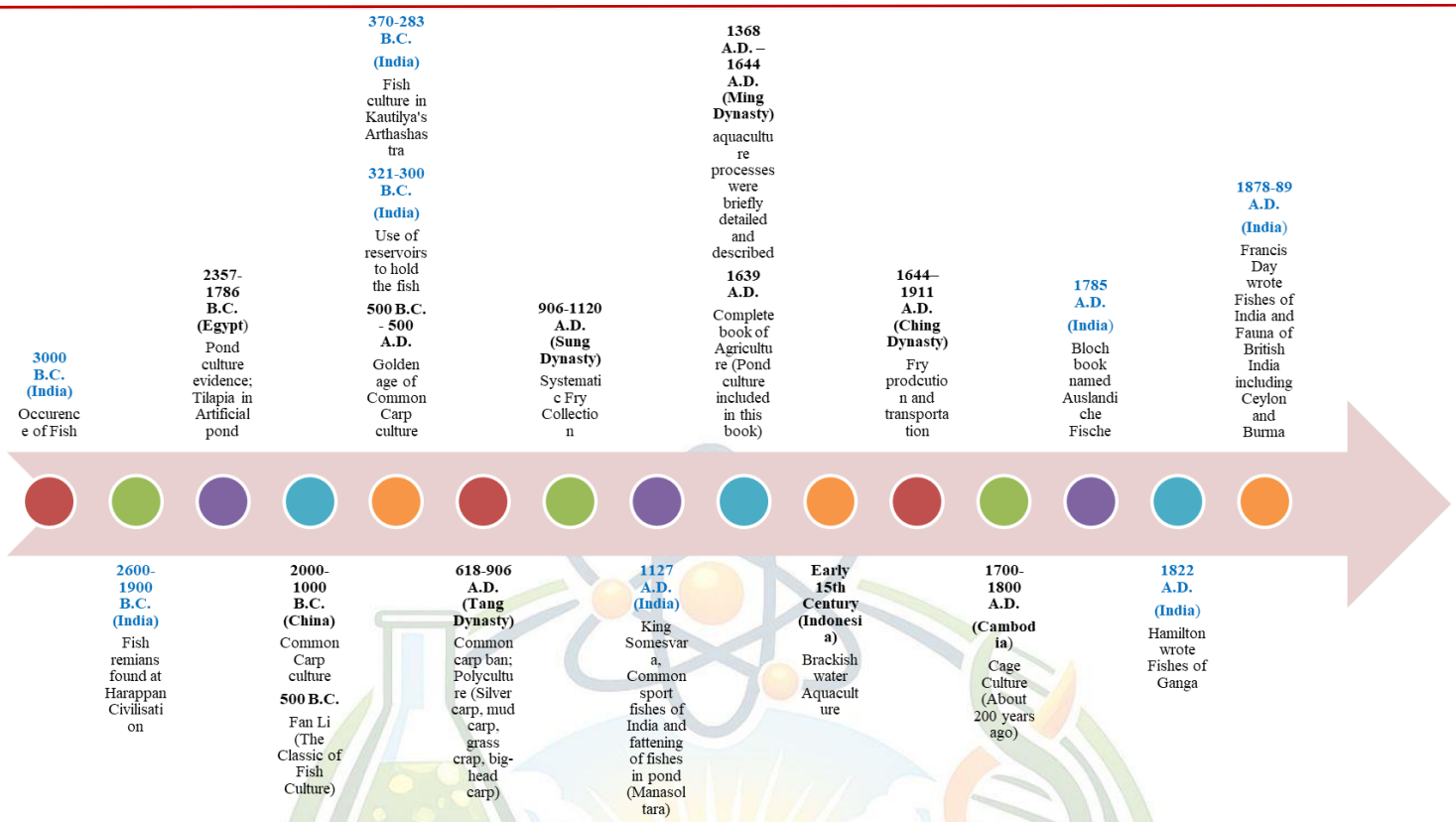


Fig 5: Timeline of events depicting the history of aquaculture in India and the world.

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Speed Breeding in Vegetable Crops: A New Approach to Accelerated Crop Improvement

Article ID: 73508

Dr. Sumit P. Umbarkar[1]

[1]Ph. D. Horticulture (Vegetable Science), Department of Vegetable Science, Faculty of Horticulture, Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola, Maharashtra.

Abstract

Vegetable crops are critical for nutritional security, farm income, and sustainable agriculture. However, conventional breeding in vegetables is often constrained by seasonal limitations and long generation cycles. Speed breeding, which involves manipulation of photoperiod, light intensity, and temperature under controlled environments, has emerged as an effective approach to accelerate crop improvement. By enabling up to four to six generations annually in several vegetable species, it significantly shortens breeding timelines and enhances selection efficiency. This review outlines the principles and physiological basis of speed breeding, its applications in major vegetable crops, integration with molecular breeding tools, and relevant case studies. The approach holds tremendous promise for farmers, students, and researchers seeking rapid and resilient horticultural solutions.

Introduction

Vegetable cultivation plays a central role in improving livelihoods and ensuring dietary diversity. Yet, the development of superior vegetable varieties—whether for higher yield, disease resistance, nutritional enrichment, or climate tolerance—traditionally requires several years of breeding work. In an era of climate change, increasing pest pressure, and rising food demand, breeders need faster tools. Speed breeding offers a scientific solution by shortening the seed-to-seed cycle through environmental manipulation. Initially popularized through pioneering research by Blinkov *et. al.*, (2025), the concept has now expanded into horticultural crops worldwide.

What is Speed Breeding?

Speed breeding is a technique that accelerates plant growth by manipulating:

1. Photoperiod (20–22 hours light/day)
2. Light intensity and spectrum (LED systems)
3. Temperature and humidity
4. Nutrient management
5. Early seed harvesting.

Under conventional conditions, many vegetable crops produce 1–2 generations annually. Speed breeding can increase this to 4–6 generations in suitable crops.

Why Speed Breeding Matters for Vegetable Crops?

Vegetables — such as tomato, pepper, cabbage, lettuce, and amaranth have traditionally long breeding cycles, especially when developing complex traits like disease resistance or heat tolerance. Extended juvenile periods, narrow planting windows, and seasonal limitations can slow varietal improvement. Speed breeding addresses these limitations by:

1. Increasing the number of generations per year, speeding up breeding progress.
2. Reducing time to release improved varieties for farmers.
3. Enabling quick responses to emerging disease threats or climate-related challenges.
4. Facilitating integration with modern tools such as genomic selection, marker-assisted selection, and gene editing.



Fig. 1: Concept of Speed Breeding Setup

How Speed Breeding Works?

Although speed breeding protocols can vary by crop and objective, the general principles include:

1. Extended Photoperiod (Light Duration): Most speed breeding systems use up to 20–22 hours of daily light, allowing plants to photosynthesize and grow almost continuously. This reduces the vegetative and reproductive phases.

2. Controlled Temperature & Humidity: Ideal temperatures are maintained to support rapid growth and early flowering. Humidity and ventilation are controlled to reduce disease risk in enclosed environments.

3. Early Seed Harvest: Breeders may harvest immature seeds — before they would normally mature- germinate them, and use them for the next generation. This further shortens the generation cycle.

4. Optimized Nutrition & Density: Nutrient supply, spacing, and substrate selection are adjusted to support rapid growth without stress.

5. Controlled Environment Facilities: Speed breeding is often conducted in growth chambers, greenhouses, or poly-houses with supplemental lighting and climate control.

These elements combine to reduce the "seed to seed" period significantly compared to conventional field breeding.

Applications in Major Vegetable Crops

1. Tomato: Speed breeding allows up to 5-6 generations per year in tomato. The World Vegetable Center has used this system to develop heat-tolerant and disease-resistant tomato lines.

Applications include:

a. Tomato leaf curl virus resistance
b. Bacterial wilt resistance
c. Enhanced lycopene content

2. Chilli and Sweet Pepper (Capsicum spp.): Capsicum breeding benefits from reduced juvenile phases under extended lighting. Key breeding goals include:

a. Anthracnose resistance
b. Viral resistance
c. Heat tolerance
d. High capsaicin varieties

3. Brassicas (Cabbage, Broccoli, Cauliflower): Generation time can be reduced from 12–18 months to less than 6 months under optimized conditions. This enhances breeding for:

a. Black rot resistance
b. Clubroot resistance
c. Quality improvement
d. Biofortification.

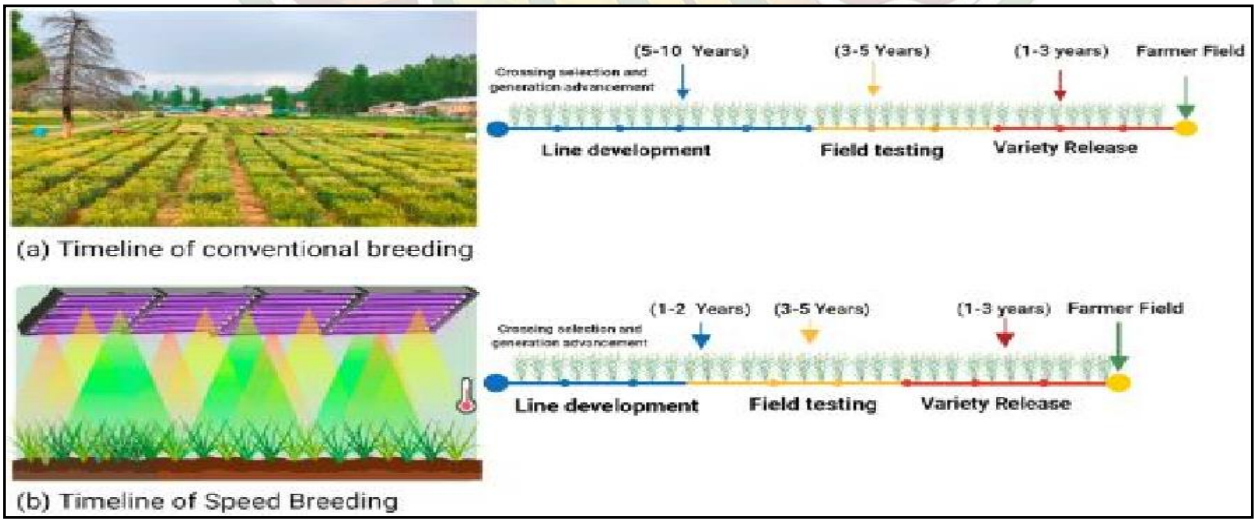


Fig. 2: Comparison of conventional breeding cycle vs. speed breeding cycle

Integration with Modern Breeding Technologies

Speed breeding becomes more powerful when integrated with:

1. Marker-Assisted Selection (MAS)
2. Genomic Selection
3. CRISPR-based genome editing

4. Doubled haploid technology

Faster generation turnover means quicker fixation of edited or selected traits.

Case Study- Accelerated Vegetable Improvement

The World Vegetable Centre established a dedicated speed breeding facility to accelerate tomato and pepper breeding. Multiple generations per year allow faster development of climate-resilient varieties suitable for smallholder farmers. This demonstrates real-world application beyond experimental research.

This cutting-edge centre uses precision control of light, temperature, and humidity to cultivate multiple generations annually — enabling breeders to develop heat-tolerant and disease-resistant lines much more rapidly than traditional breeding would allow. The facility's focus is on traits important for smallholder farmers in Asia and Africa, such as tolerance to high temperatures and resistance to emerging pests and diseases. By increasing the number of breeding cycles per year, researchers can test many more genetic combinations and deliver improved varieties in shorter times. This practical application shows how speed breeding accelerates the development of climate-resilient vegetable varieties that directly benefit farmers facing unpredictable weather and disease pressures.

Practical Implementation Model: A basic speed breeding unit typically requires a polyhouse/greenhouse, LED lighting with programmable timers, temperature control, rapid seed drying and germination facilities, and skilled staff. Low-cost adaptations can be achieved by modifying existing protected cultivation structures to extend light duration

Challenges & Future Prospects: Implementing speed breeding poses challenges like high initial infrastructure costs, energy requirements, and the need for crop-specific optimization, field validation, and technical expertise. It's crucial to note that speed breeding should complement, not replace, traditional field trials. However, future prospects look promising with potential developments in AI-based growth monitoring, automated phenotyping, vertical farming integration, and climate simulation chambers. As LED technology becomes more affordable, adoption is expected to expand, especially in developing nations, revolutionizing crop development and food security.. With ongoing advancements, speed breeding can become a game-changer in agriculture, enabling faster and more efficient crop improvement. This can lead to increased crop yields, improved disease resistance, and enhanced nutritional content, ultimately benefiting global food security and sustainability.

Conclusion

Speed breeding represents a paradigm shift in vegetable crop improvement. By accelerating generation cycles, it enhances breeding efficiency, shortens variety development timelines, and strengthens climate resilience. For horticulture, where rapid response to environmental and market changes is critical, speed breeding offers a powerful and practical solution. With proper infrastructure and integration with modern genetic tools, it can transform the future of vegetable breeding.

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Carbon Farming: A Novel Approach for Income Generation and Climate Resilience

Article ID: 73509

Haripriya Ngairangbam[1]
[1]Department of Agronomy, School of Agriculture, Lovely Professional University, Phagwara, Punjab, India.

Summary
Carbon farming is a novel method of farming aimed at enhancing soil health and farm productivity. This method also helps in reducing climate change by capturing atmospheric carbon dioxide. Agroforestry, cover cropping, and reduced tillage, are some of the various techniques of practicing carbon farming, all aimed at promoting sustainable land management with the potential of generating economic benefits to farmers in the form of carbon credit markets. With increasing challenges day by day in the agricultural sector due to climate change, carbon farming has become one of the most important strategies that not only supports environmental goals but also offers a good source of income for farmers.

Introduction
Carbon farming is a technique that has developed due to the growing consciousness of the problems of global warming and a growing realization of the necessity to have sustainable agriculture. Historically speaking, agriculture has played a major role in releasing greenhouse gases, researchers and policymakers in this context have been keen to identify ways in which they can ensure we reduce such gases, at the same time improve the quality of soil and farm yield.

The early agricultural development strategies focused on production in large quantities through mass production, and in most cases, these methods were detrimental to the environment. With the rise of industrial farming, farmers increasingly concentrated on short-term harvesting, and this approach resulted in agricultural activities that were not healthy to the long-term maintenance of soil and its retaining capacity of carbon (Garthwaite, 2025). However, as climate change talks started in the late 20th century, a slow transition has occurred to practices that integrate ecological ideas into agriculture, which came to be known as carbon farming.

With the development in climate impact studies, some studies have demonstrated the need to employ adaptive farming practices that are both climate resilient and economically viable. These projects underline the importance of informed decision-making in making adaptation investments and reducing the risks of climate variability.

The carbon farming discussion has since developed into encompassing some broad practices which are meant to maximize the benefit of agricultural systems in regard to their carbon sequestration capacity, which includes; cover cropping, no-till farming and agro forestry (Ridge, 2021). Such practices are not only regarded as means of fighting climate change, but they also provide the opportunity to the farmers to get into the carbon market and enhance financial stability.

Methods of Carbon Farming
Carbon farming involves numerous activities that are directed at mitigating the amount of atmospheric carbon dioxide by means of better agricultural practices. These practices do not only help in mitigating climate changes but also help in improving the health of the soil and increase the productivity of farming.

1. Agroforestry: Agroforestry integrates trees into agricultural systems to create a symbiotic environment that benefits crops and livestock. This technique sequesters carbon deep in the soil and protects crops and livestock from adverse weather, thereby enhancing farm productivity, and preventing soil erosion. (Jain, 2021; Plastina, 2022)

2. Cover Cropping: Cover cropping is the process of growing crops that actually help improve and protect the soil in which they are grown instead of trying to make profit from harvest. These crops will limit disturbance to the surface area by helping trap nutrients and cycling them back into the soil. Increase of organic matter helps increase soil organic carbon helping to reduce CO2 from the atmosphere. (Ridge, 2021)

3. Reduced Tillage: By minimizing soil disturbance through no-till or strip-till practices, soil organic carbon is retained by leaving residual crops and reducing soil turnover. It also decreases erosion and turnover allowing for better air flow and less destruction of organisms living in the soil. Although pests and nutrients can become an issue at first with not disturbing the soil, overall less tillage has been proven to create more resilient and productive farms. (Ridge, 2021; Plastina, 2022)

4. Companion Cropping: Companion cropping is the practice of planting multiple species of crops together to benefit the others growing around them. This practice creates natural pest barriers and enriches the soil. For example, using nitrogen-fixing legumes with nutrient-demanding crops can reduce reliance on synthetic fertilizers and improve overall soil health (Jain, 2021).

5. Soil Amendments: Soil improvements like compost and biochar to sequester carbon and improve soil quality. These products increase soil organic content, water retention, and biological activity, resulting in healthier plants that better

resist pests and diseases. These soil amendments are crucial to carbon farming, promoting soil health and mitigating climate change effects. (Pudasaini, 2025; Plastina, 2022)

Through such strategies, the farmers will be able to ensure carbon sequestration as well as enhance their farming systems and even earn millions of dollars in carbon markets (Jain, 2021; Ridge, 2021).

Economic Aspects

Carbon farming provides economic opportunities for farmers while helping to address climate change. Farmers can earn money by selling carbon credits they create when implementing climate-smart agriculture practices. Carbon credits are generated when one tonne of carbon dioxide equivalent is avoided or removed from the atmosphere. Farmers can sell their credits on voluntary carbon markets. Income earned from carbon markets can help farmers diversify their income streams and increase their overall farm profitability and financial stability.

1. Profitability and Cost Savings: Farmers who have transitioned to regenerative agriculture have experienced revenue increases of 15% to 25%. Farmers participating in the study published in 2023 reported average net farm incomes increased by $65 per acre, with some farmers increasing net revenue by up to $425 per acre. This increase in profitability is largely due to decreases in farm operation costs and an increase in productivity as a result of healthier soils. (Garthwaite, 2025)

2. Carbon Credits and Market Dynamics: Carbon credit value is set by market supply and demand. Farmers can boost income through practices like no-till farming, cover cropping, and agroforestry, which sequester carbon, improve soil health, and reduce costs. However, some carbon farming may need significant government support, such as subsidies, to be economically viable.

3. Financial Incentives and Support: Green finance and grants boost the economic viability of carbon farming, lowering the initial costs of adopting sustainable practices. Furthermore, the improved crop quality resulting from these techniques can command premium market prices from consumers who value sustainably produced goods.

Environmental Impact

Carbon farming significantly influences environmental sustainability by enhancing soil health and resilience, while also addressing climate change challenges. The implementation of carbon farming practices leads to numerous benefits, including improved soil carbon storage, erosion control, and the creation of habitats that support diverse ecosystems.

1. Soil Resilience and Health: Carbon farming boosts soil resilience, vital for withstanding extreme weather like droughts and floods. (Reeling, 2021) Healthier soils, with improved structure and fertility, lead to higher yields and reduced erosion. Practices like cover cropping and crop rotation enrich soil and boost moisture retention, better equipping it to handle weather changes. Additionally, the use of organic fertilizers and reduced tillage further contributes to increased soil health, supporting beneficial microorganisms and insects that are vital for a balanced ecosystem.

2. Carbon Sequestration: Carbon farming sequesters atmospheric CO_2, effectively reducing greenhouse gas emissions. Practices that boost soil organic matter also improve soil water retention and resilience. (Pudasaini, 2025) Carbon-rich soils reduce greenhouse gas emissions and boost crop productivity. This approach can help farmers become carbon-negative, absorbing more CO_2 than they emit, and positively contributing to global climate goals.

3. Biodiversity and Ecosystem Benefits: Carbon farming benefits biodiversity by promoting species habitats, creating a more resilient ecosystem. This approach safeguards the environment and offers farmers new revenue through carbon credit sales, encouraging sustainable agriculture.

Challenges and Barriers

Despite its potential benefits, carbon farming adoption faces barriers like high initial costs, non-uniform guidelines, and uncertain carbon credit demand and pricing volatility. Despite these challenges, evolving carbon markets offer farmers a promising chance to diversify income and promote environmental sustainability.

Financial Risks

Carbon farming faces significant financial risks for farmers, including high upfront costs and uncertain market returns. The variable nature of 'additionality' complicates financial choices, leading some farmers to favour projects with better customer service over potential profit and environmental benefit. Technical complexity and market volatility further discourage adoption without guaranteed investment returns.

Complexity and Administrative Costs

Carbon farming faces high administrative costs, mainly due to the extensive monitoring, reporting, and verification needed for carbon credit compliance. While carbon programs typically cover the costs of verifying soil carbon, the technical difficulty of accurate measurement remains a significant barrier for farmers.

Demand Uncertainty and Market Dynamics

Demand uncertainty in carbon markets is a major hurdle. Corporations' vague short- and medium-term carbon credit purchasing plans, despite long-term neutrality pledges, heighten the perceived risk for farmers who must commit to multi-year credit generation contracts. (Randall, 2025)

Future Perspectives

Future outlook on carbon farming suggests that in the context of increasing impacts of climate change, it offers a viable option in both environmental mitigation and economic stability of the agricultural sector, but successful adoption would be limited by proper risk management and perception of risks by farmers; use of precision agriculture and data-driven technology can lead to more efficient carbon sequestration, and close and close collaboration between governments and the agricultural sector will be necessary to disseminate knowledge and implement policies to support them; finally, improved management of risks and perception of risk by farmers would lead to successful adoption of the practice.

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Post-Harvest Losses and Emerging Opportunities in Agribusiness in India

Article ID: 73510

Pavan D S[1], Sushma Purada[2]

[1]Former MBA(Agribusiness)in Agribusiness Management, Department of Agribusiness Management, University of Agricultural Sciences, Dharwad, Karnataka, India, 580005.

[2]Ph. D. Scholar, Department of Agribusiness Management, University of Agricultural Sciences, Bengaluru, Karnataka, India, 560065.

Introduction

Post-harvest losses (PHL) refer to both quantitative and qualitative reductions in agricultural produce that occur after harvesting during stages such as handling, storage, transportation, processing, and marketing. These losses significantly affect food availability, reduce farmers' income, and lower the overall efficiency of the agricultural supply chain. According to estimates by the Food and Agriculture Organization, nearly 13.3% of food produced globally is lost after harvest, with fruits and vegetables being the most vulnerable.

Losses occur at multiple stages of the supply chain, including harvesting, threshing, storage, processing, transportation, and marketing. The causes are broadly categorized into biological, environmental, and operational factors. Biological factors include respiration, transpiration, microbial growth, and ethylene production, which accelerate spoilage. Environmental conditions such as temperature fluctuations, humidity, and atmospheric changes also contribute to deterioration. Additionally, improper handling, inadequate storage facilities, and poor infrastructure further aggravate these losses.

To address these challenges, various strategies have been implemented at different levels. At the farm level, improved harvesting techniques, scientific drying methods, and proper storage practices can minimize losses. At the market level, better transportation systems, grading, packaging, and the development of cold chain infrastructure play a vital role. Capacity-building initiatives, including farmer training programs, awareness campaigns, and technology demonstrations, are equally important in strengthening post-harvest management practices.

Post-harvest losses have far-reaching economic and social consequences, such as reduced farmer earnings, increased food insecurity, and inefficient use of valuable resources like water, land, and energy. However, these challenges also present promising opportunities in the agribusiness sector. Areas such as cold chain logistics, modern warehousing, food processing, innovative packaging, nanotechnology applications, waste utilization, and agri-consultancy services offer significant potential for growth and investment.

Several successful initiatives and organizations, such as Sahyadri Farms and Ecozen Solutions, demonstrate how the adoption of innovative technologies, improved storage systems, and value addition can effectively reduce losses while generating profitable business models. Government programs like Pradhan Mantri Kisan SAMPADA Yojana, Mission for Integrated Development of Horticulture, and RKVY-RAFTAAR further support the development of post-harvest infrastructure and promote agri-entrepreneurship.

In conclusion, minimizing post-harvest losses is crucial for enhancing food security, improving farmer livelihoods, and promoting sustainable agriculture. With the integration of advanced technologies, efficient management practices, and supportive government policies, post-harvest challenges can be transformed into viable and profitable agribusiness opportunities.

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India's Fertilizer Industry: Policies, Subsidies, and Agribusiness Outlook

Article ID: 73511

Pavan D S[1], Sushma Purada[2]

[1]Former MBA(Agribusiness)in Agribusiness Management, Department of Agribusiness Management, University of Agricultural Sciences, Dharwad, Karnataka, India, 580005.

[2]Ph. D. Scholar, Department of Agribusiness Management, University of Agricultural Sciences, Bengaluru, Karnataka, India, 560065.

Introduction

India's fertilizer industry plays a pivotal role in ensuring food security, improving agricultural productivity, and supporting rural livelihoods. As one of the world's leading agricultural economies, India ranks as the second-largest consumer and third-largest producer of fertilizers globally. The balanced application of essential nutrients such as nitrogen (N), phosphorus (P), and potassium (K) is crucial for maintaining soil health and sustaining crop yields. However, rising demand, regional imbalances in nutrient consumption, and dependence on imports for certain fertilizers continue to shape the sector's dynamics.

Evolution

The evolution of the fertilizer industry in India dates back to the early twentieth century, with rapid expansion occurring after independence. This growth was driven by the establishment of major manufacturing units and institutional support from organizations such as Fertilizer Corporation of India, which played a key role in strengthening domestic production and distribution systems. Over time, the sector has witnessed active participation from public, cooperative, and private enterprises. Domestic production, particularly of urea, has grown steadily due to policy reforms, investments in new plants, and the revival of previously closed units. Despite these advancements, India remains dependent on imports of fertilizers like diammonium phosphate (DAP) and muriate of potash (MOP), making the sector vulnerable to global price fluctuations and supply uncertainties.

Government policies have significantly influenced the development and functioning of the fertilizer industry. Earlier mechanisms such as the Retention Pricing Scheme ensured fair returns to manufacturers while keeping fertilizers affordable for farmers. Subsequent reforms, including the New Pricing Scheme and the New Urea Policy 2015, aimed to enhance energy efficiency, encourage domestic production, and reduce the subsidy burden. While urea remains under price regulation, phosphatic and potassic fertilizers are governed by the Nutrient Based Subsidy system, which promotes balanced nutrient application.

The introduction of the Direct Benefit Transfer system has improved transparency and efficiency in subsidy distribution. Under this mechanism, subsidies are released to companies only after fertilizers are sold to farmers through point-of-sale devices at retail outlets. Additionally, initiatives such as Pradhan Mantri Bhartiya Jan Urvarak Pariyojana and PM-PRANAM Scheme aim to improve fertilizer accessibility, promote balanced usage, and reduce excessive reliance on chemical fertilizers. Technological advancements, including nano fertilizers developed by Indian Farmers Fertiliser Cooperative Limited, represent a significant step toward enhancing nutrient use efficiency and encouraging sustainable agricultural practices.

The fertilizer sector also has important implications for agribusiness. Subsidies lower input costs, making fertilizers more accessible to farmers and thereby boosting productivity and farm incomes. Policy support encourages investments by fertilizer companies and agribusiness firms, leading to expansion in production capacity and market opportunities. Increasing demand for fertilizers also strengthens supply chains, including distribution networks, logistics, and agri-input retail systems. Moreover, innovations such as nano fertilizers, biofertilizers, and digital monitoring technologies are creating new avenues for agribusiness growth and technological advancement.

Conclusion

In conclusion, India's fertilizer industry is closely linked to agricultural development, food security, and farmer welfare. While government policies and subsidies have played a critical role in ensuring fertilizer availability and supporting production, the long-term sustainability of the sector will depend on balanced nutrient management, technological innovation, efficient subsidy mechanisms, and environmentally responsible agribusiness practices.

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Powering Agribusiness Growth: How Startup India Fuels Innovation and Scale

Article ID: 73512

Pavan D S[1], Sushma Purada[2]

[1]Former MBA(Agribusiness)in Agribusiness Management, Department of Agribusiness Management, University of Agricultural Sciences, Dharwad, Karnataka, India, 580005.

[2]Ph. D. Scholar, Department of Agribusiness Management, University of Agricultural Sciences, Bengaluru, Karnataka, India, 560065.

Introduction

Entrepreneurship and innovation have emerged as key drivers in transforming the agricultural sector and enhancing the efficiency of agribusiness systems in India. Agriculture continues to be a primary source of livelihood for a significant portion of the population; however, the sector faces persistent challenges such as low productivity, inefficient supply chains, limited adoption of modern technologies, and weak market linkages. Addressing these issues requires a dynamic entrepreneurial ecosystem supported by policy interventions and technological advancement.

In this context, the Government of India launched the Startup India Initiative on 16 January 2016 to foster innovation, promote startups, and generate employment opportunities. The initiative aims to create a robust ecosystem that nurtures new enterprises by reducing regulatory barriers and facilitating access to resources. It is implemented by the Department for Promotion of Industry and Internal Trade under the Ministry of Commerce and Industry.

The Startup India program offers a wide range of benefits, including simplified regulatory processes, tax exemptions, funding assistance, incubation support, and networking opportunities. Financial schemes such as the Startup India Seed Fund Scheme, Fund of Funds for Startups, and Credit Guarantee Scheme for Startups provide crucial capital support to early-stage ventures, enabling them to scale operations and innovate effectively.

Within the agribusiness sector, the initiative has significantly accelerated the growth of agri-tech startups. These enterprises leverage advanced technologies such as artificial intelligence (AI), the Internet of Things (IoT), drones, and data analytics to improve agricultural productivity and supply chain efficiency.

Such innovations enable farmers to optimize input use, minimize post-harvest losses, and access markets more efficiently. Additionally, digital platforms developed by these startups facilitate direct connections between farmers and consumers, enhancing price transparency and increasing farmer incomes.

Several successful startups, including Ninjacart, DeHaat, AgroStar, and Fasal, demonstrate how innovative business models can transform agricultural value chains. Furthermore, incubation centers such as ICAR-NAARM and C-CAMP play a vital role in strengthening the ecosystem by offering mentorship, technical expertise, and business incubation support to emerging entrepreneurs.

Conclusion

In conclusion, the Startup India initiative has made a significant contribution to the growth of agribusiness startups in India.

By promoting innovation, improving access to finance, and encouraging the adoption of advanced technologies, the program is helping to build a more efficient and resilient agricultural value chain. This, in turn, supports sustainable agribusiness development and enhances the overall competitiveness of the agricultural sector.

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An Overview of Common Bacterial Blight of Beans Caused by *Xanthomonas axonopodis* pv. *phaseoli*

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Aamina Nazir[1], Waseem Ali Dar[1], Neelofar Majeed[1], Muzammil Khursheed[1], Muneeba Hassan[1], Piyush Kumar[1]

[1]Division of Plant Pathology, FoA, Wadura, Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir, Wadura-193201, J &K, India.

Abstract

Common bacterial blight (CBB) of bean is one of the most damaging bacterial infections affecting *Phaseolus vulgaris* over the world. The primary cause of the disease is *Xanthomonas axonopodis* pv. *phaseoli* (Xap) and its variant, *Xanthomonas axonopodis* pv. *phaseoli* var. *fuscans*. These Gram-negative bacteria infect aerial plant tissues, causing distinctive water-soaked lesions surrounded by chlorotic halos that can result in significant defoliation and yield decrease. The disease is primarily seed-borne, spreading by rain splash, irrigation water, and contaminated agricultural implements. Environmental factors such as high temperatures and humidity encourage bacterial proliferation and disease outbreaks. Advances in molecular biology have helped us better understand pathogen virulence mechanisms, host pathogen interactions, and strain genetic diversity. Sustainable disease control requires integrated disease management systems that include resistant cultivars, biological control agents, cultural practices, and the limited use of bactericides. This study summarises current knowledge about the taxonomy, epidemiology, host resistance, and management options of *Xanthomonas axonopodis* pv. *Phaseoli*.

Introduction

Beans (*Phaseolus vulgaris* L.) are an important source of nutritional protein, fibre, and minerals for people in underdeveloped nations. Common bean serves as a major nutrient source for nearly 500 million people in parts of Africa and Latin America, providing about 65% of total protein and 32% of daily energy intake. It is also rich in essential minerals and nutrients, including iron, phosphorus, magnesium, potassium, calcium, zinc, and folate, which contribute to a balanced and healthy diet. Global bean output reaches 30 million tonnes per year, and the commodity is critical to food security and sustainable agriculture (Broughton *et al*., 2003). Several bacterial infections, including common bacterial blight (CBB), have a significant economic impact on bean farming. The disease is predominantly caused by *Xanthomonas axonopodis* pv. *phaseoli* and its closely related variety, *X. axonopodis* pv. *phaseoli* var. *fuscans* (Behlau *et al*., 2006). Common bacterial blight is widespread in temperate and tropical countries, especially in locations with warm and humid climates. Yield losses can range from 10 to 45 percent depending on climatic circumstances, pathogen strain, and host susceptibility (Schwartz *et al*., 2005 and Miklas *et al*., 2006).

The disease infects the leaves, stems, pods, and seeds, impacting both yield and seed quality. The bacteria are transmitted through seeds, contaminated seed lots provide a significant supply of primary inoculum and contribute to the pathogen's long-distance spread (Darrasse *et al*., 2007). Understanding the pathogen's biology and epidemiology is critical for creating successful disease control measures.

Taxonomy and Systematics

Xanthomonas is a complex group of Gram-negative bacteria that infects over 350 plant species (Ryan *et al*., 2011). The genus classification has changed multiple times as molecular phylogenetic techniques have advanced. The taxonomical classification of the pathogen was presented in Table 1. Bacterium *phaseoli* was initially identified as the cause of common bacterial blight before being reclassified as *Xanthomonas campestris* pv. *phaseoli*. Later DNA-DNA hybridisation and molecular phylogenetic research led to its reclassification as *xanthomonas axonopodis* pv. *phaseoli* (Vauterin *et al*., 1995). There are two primary variations related with common bacterial blight that is *Xanthomona axonopodis* pv. *phaseoli* (XAP) and *Xanthomonas axonopodis* pv. *phaseoli* var. *fuscans* (Xapf). The latter produces brown pigment on culture medium and, while genetically unique, causes identical illness signs (Behlau *et al*., 2006).

Table. 1: Taxonomic hierarchy of *Xanthomonas campestris* pv. *Phaseoli* (Hibbett *et al*., 2007):

Rank	Classification
Domain	Bacteria
Phylum	Proteobacteria
Class	Gammaproteobacteria
Order	Xanthomonadales
Family	Xanthomonadaceae
Genes	Xanthomonas

Species	*Xanthomonas axonopodis*
Pathovar	Phaseoli

Morphological and Physiological Characteristics

Xanthomonas axonopodis pv. *phaseoli* cells are Gram-negative rods measuring around 0.4-0.7 µm × 1-2 µm. They are motile due to a single polar flagellum (Schwartz *et al.*, 2005). When cultivated on nutrient agar, colonies are yellow and mucoid, convex and smooth, and round with complete edges. The yellow colouration is caused by the formation of *xanthomonadin* pigments, which protect the bacteria from photodamage and oxidative stress (Goel *et al.*, 2002). Another important characteristic of *Xanthomonas* species is the formation of extracellular polysaccharides (EPS), specifically xanthan gum. EPS promotes bacterial adhesion, biofilm formation, protection against plant defence responses, and increased virulence (Ryan *et al.*, 2011). The bacterium is absolutely aerobic and thrives best at temperatures between 28°C and 30°C.

Host Range

Xanthomonas axonopodis pv. *phaseoli's* principal host is common bean (*Phaseolus vulgaris*), but the pathogen has also been found in *Phaseolus coccineus* (runner bean), *Vigna radiata* (mung bean), *Glycine max* (soybean), and *Vigna unguiculata* (cowpea). These alternate hosts could act as reservoirs for pathogen survival in agroecosystems (Schwartz *et al.*, 2005).

Disease Symptoms

Symptoms are often found on all aerial sections of the plant.

1. Leaf Symptoms: The first symptoms are tiny, water-soaked sores on the leaves. These lesions grow and become necrotic, with conspicuous yellow halos typical of Common bacterial blight (Schwartz *et al.*, 2005).



Fig 1: Leaf Symptoms

2. Stem and Petiole Symptoms: Infected stems include dark streaks or elongated lesions, which can lead to tissue breakdown and plant weakness. Seedling stems may develop water-soaked, sunken lesions that enlarge and turn into reddish streaks. As the disease progresses, affected stems often crack and may become girdled by water-soaked cankers or rot. During rain or strong winds, weakened plant tops may break. A high bacterial population in the xylem can lead to wilting due to vessel blockage or cell wall degradation. Under humid conditions, yellowish bacterial ooze may appear on lesions of pods, leaves, stems, and cotyledons, which later dries to form a crust (Schwartz *et al.*, 2005).



Fig 2: Stem Symptoms

3. Pod Symptoms: Pods infected through the plant vasculature develop water-soaked lesions with a central yellow or cream-colored bacterial colony. Pods form deep reddish-brown sores. Bacterial exudates can be seen on the surface of diseased pods in humid conditions. If infection occurs during pod and seed development, seeds may rot or become shriveled. Under severe infection, entire pods may shrivel, and seeds may either fail to develop or remain shriveled (Buruchara *et al.*, 2010).



Fig 3: Pod Symptoms

4. Seed Infection: Infected pod seeds can become discoloured, shrivelled, or polluted inside, making them a significant source of primary inoculum (Darrasse *et al.*, 2007). Seed infection occurs when bacteria enter through pod sutures via the pedicel or vascular system and move into the funiculus through the raphe, reaching the seed coat. The micropyle may also serve as an entry point, while direct penetration of the seed coat has not been reported. Infection through the funiculus may cause discoloration only at the hilum, and infected seeds can occur even in symptomless pods. On white or light-colored seeds, symptoms appear as butter-yellow spots but are difficult to detect on darker seeds. Seedlings from severely infected seeds may show damaged growing tips, stunting, or death (Buruchara *et al.*, 2010).

Disease Cycle and Epidemiology

The epidemiology of common bacterial blight is heavily influenced by environmental factors and agricultural methods. The life cycle of pathogen was presented in Fig. 4.

1. Primary Inoculum: The pathogen primarily lives in infected seeds, plant detritus, and volunteer bean plants (Schwartz et al., 2005).

2. Infection and Colonization: The bacterium enters plant tissues via natural holes like stomata and hydathodes, as well as wounds caused by mechanical injury or insect feeding (Darrasse et al., 2007).

3. Secondary Spread: Secondary transmission occurs via rain splash, irrigation water, wind-driven rain, infected instruments, and human activities.

4. Environmental Factors: Warm temperatures (25-30°C) and high humidity promote illness development and epidemic breakouts (Akhavan *et al.*, 2013).

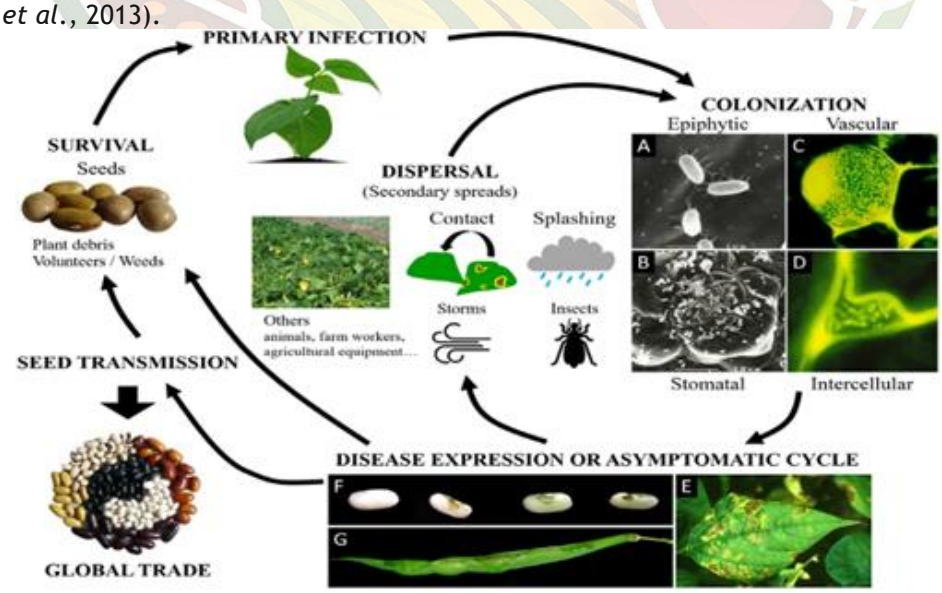


Fig 4: Life Cycle

Integrated Disease Management

Integrated disease management involves combining multiple control measures to maintain disease levels below the economic threshold. This approach is preferred due to concerns about the environmental impact of chemicals and the limited effectiveness of relying on a single control method. It integrates biological, cultural, physical, and mechanical practices to reduce disease severity, particularly during critical growth stages. Effective management of common

bacterial blight in beans includes crop rotation, field sanitation, use of healthy or treated seeds, resistant or tolerant varieties, avoidance of plant stress and wounds, and proper bactericide application. Among these, the use of resistant varieties along with appropriate cultural practices and chemical seed treatment is considered one of the most effective strategies for minimizing yield losses (Popovic *et al.*, 2010).

1. Cultural Practices: Cultural control remains an important aspect of illness management. Recommended procedures include using certified disease-free seeds, rotating crops every 2-3 years, removing diseased crop residues, and avoiding overhead irrigation (Schwartz *et al.*, 2005).

2. Host Resistance: The most efficient and ecologically friendly control method is breeding for resistant crops. A number of resistance sources, including resistant genotypes like BAT 93, PI 319443 (tepary bean), and HR45, which have been widely used as sources of resistance to common bacterial blight caused by *Xanthomonas axonopodis* pv. *phaseoli*, have been found in bean germplasm collections and incorporated into commercial cultivars (Miklas *et al.*, 2006).

3. Chemical Control: Copper-based bactericides, like copper hydroxide and oxychloride, are frequently used to manage bacterial populations on plant surfaces. Applying 0.3% (3 g L^{-1}) copper oxychloride and 100 ppm streptocycline to common beans has been shown to significantly lessen disease severity in field settings (Miklas *et al.*, 2006 and Suchita *et al.*, 2025). In experimental research, antibiotics like streptomycin or streptocycline are usually used at concentrations between 100 and 500 parts per million. Nevertheless, their usage is becoming more limited because of worries about the emergence of antibiotic resistance and the effects on the environment.

4. Biological Control: According to Sallam (2011) and Mageshwaran *et al.*, (2012), biological control agents like *Rahnella aquatilis* and *Paenibacillus polymyxa* have demonstrated antagonistic action against *Xanthomonas axonopodis* pv. *phaseoli* by generating antimicrobial chemicals and causing systemic resistance in host plants. These biocontrol agents, which have been shown to considerably lessen disease severity under experimental settings, are usually used as seed treatments or foliar sprays at concentrations of 10^8–10^9 CFU mL^{-1} or as talc-based formulations at 10 g kg^{-1} seed.

Future Perspectives

Recent developments in genomes, transcriptomics, and proteomics are shedding fresh light on the molecular pathways underlying *Xanthomonas* pathogenicity and host resistance. Future research should concentrate on genome-based pathogen surveillance, virulence gene identification, CRISPR diagnostics, and long-term resistance breeding. These measures will aid in the long-term management of common bacterial blight in bean production systems.

Conclusion

Xanthomonas axonopodis pv. *Phaseoli* is a significant bacterial disease that causes frequent bacterial blight in beans globally. The disease has a considerable impact on yield and seed quality, particularly in warm and humid circumstances. The pathogen has diverse virulence pathways that include type III secretion systems, extracellular enzymes, and polysaccharide synthesis. Effective disease management necessitates an integrated approach that incorporates resistant cultivars, cultural methods, biological control agents, and the prudent use of bactericides. Continued study into pathogen genomes and host-pathogen interactions will aid in the development of long-term strategies for managing this economically significant disease.

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Crop Diversification in Telangana

Article ID: 73514

K. Sridhar[1], K. Mamatha[2], A. Sriram[2], K. Sravanti[3]
[1]AICRP on IFS, Rajendranagar
[2]Regional Agricultural Research Station, Palem,
[3]Agricultural College, Palem
Professor Jayashanakar Telangana Agricultural University, Rajendranagar.

Introduction

Global agricultural sustainability and food security are challenged by biodiversity loss, soil degradation, and environmental pollution. To enhance agricultural sustainability and crop production, the transformation from a near monoculture to diverse cropping is recognized as a promising pathway. Crop diversification plays an important role in synergistic improvement of productivity, soil health, and ecosystem service through intercropping or crop rotation increasing spatial and/or temporal biodiversity by intentional adding plant species diversity. Crop diversification refers to the shift from monocropping to cultivation of a variety of crops and enterprises in a farming system. It involves integrating cereals, millets, pulses, oilseeds, fodder crops, horticultural crops, and allied activities such as livestock and fisheries.

In Telangana, agriculture is a major livelihood source, but it faces challenges such as climate variability, groundwater depletion, soil degradation, and market risks. Traditionally, the state has been dominated by crops like paddy and cotton, which, although productive, have led to ecological and economic imbalances when grown continuously.

Therefore, crop diversification has emerged as a key strategy for sustainable agriculture, aiming to improve farm income, ensure resource conservation, and enhance resilience to climate change.

Agro-Climatic Conditions of Telangana

Telangana lies in the **semi-arid tropical region** and is characterized by:

1. **Rainfall:** 700–1100 mm annually, mostly from the southwest monsoon
2. **Temperature:** High summer temperatures, often exceeding 40°C
3. **Soils:**
    a. Red sandy soils (low fertility and water retention)
    b. Black cotton soils (high moisture retention but prone to cracking)
4. **Irrigation Sources:** Tanks, canals, and borewells.

The state is divided into three major agro-climatic zones:

- **a. Northern Telangana Zone:** Higher rainfall, cotton-based systems
- **b. Central Telangana Zone:** Mixed cropping with moderate irrigation
- **c. Southern Telangana Zone:** Drier conditions, suitable for millets and pulses

These diverse conditions provide ample scope for region-specific crop diversification.

Present Cropping Pattern and Issues

In recent years, Telangana has experienced a shift towards monocropping, mainly:

1. **Paddy:** Expanded due to irrigation projects and government procurement
2. **Cotton:** Dominant in rainfed regions due to market demand

Problems Associated with Current Pattern:

- **a. Water Scarcity:** Paddy requires large quantities of water, leading to groundwater depletion
- **b. Soil Degradation:** Continuous cropping reduces soil fertility and organic matter
- **c. Pest and Disease Incidence:** Cotton monocropping increases pest outbreaks
- **d. Economic Risks:** Price fluctuations affect farmers' income stability

This situation highlights the urgent need for diversified and sustainable cropping systems.

Need for and Importance of Crop Diversification

1. Climate Resilience: Diversification reduces the risk of total crop failure, as different crops respond differently to climatic stresses like drought and heat.

2. Efficient Water Use: Shifting to crops like millets and pulses reduces water consumption and improves water productivity.

3. Soil Health Improvement: Crop rotation and inclusion of legumes improve soil fertility, enhance organic matter, and maintain nutrient balance.

4. Economic Stability: Multiple crops provide multiple income sources, reducing dependency on a single crop and ensuring stable earnings.

5. Nutritional Security: Diversified cropping enhances the availability of proteins, vitamins, and minerals through pulses, millets, fruits, and vegetables.

Crop Diversification Options in Telangana

1. Millets-Based Systems: Millets such as jowar, bajra, and ragi are drought-tolerant and require less water. They are highly nutritious and suitable for dryland agriculture.

2. Pulses-Based Systems: Crops like red gram, green gram, and bengal gram improve soil fertility through nitrogen fixation and have strong market demand.

3. Oilseed Crops: Groundnut, sesame, and sunflower are suitable for rainfed areas and provide good economic returns.

4. Horticultural Crops: Fruits (mango, citrus), vegetables (tomato, brinjal), and flowers (marigold) offer higher income per unit area and employment opportunities.

5. Fodder Crops: Cultivation of fodder supports livestock, which is an important component of diversified farming.

Cropping System Approaches

1. Crop Rotation: Growing different crops in sequence (e.g., paddy–pulse–oilseed) helps maintain soil fertility and break pest cycles.

2. Intercropping: Growing two or more crops simultaneously (e.g., cotton + red gram) improves resource use efficiency and reduces risk.

3. Sequential Cropping: Growing crops one after another within a year increases cropping intensity and income.

4. Integrated Farming Systems (IFS): Combining crops with livestock, poultry, fisheries, and agroforestry ensures:

a. Efficient resource recycling
b. Reduced input costs
c. Continuous income throughout the year.

Role of Technology in Diversification

Modern technologies play a crucial role in promoting diversification:

1. Micro-Irrigation: Drip and sprinkler systems improve water use efficiency

2. Protected Cultivation: Polyhouses and shade nets enhance productivity

3. Mechanization: Reduces labor costs and increases efficiency

4. Crop Modeling: Scientific tools help in irrigation scheduling and crop planning

5. Precision Farming: Optimizes use of inputs like water and fertilizers

Constraints in Crop Diversification

Despite its benefits, several challenges hinder diversification:

1. Lack of awareness and technical knowledge among farmers
2. Market uncertainty and lack of assured procurement
3. Limited availability of quality seeds and inputs
4. Inadequate storage, processing, and value addition facilities
5. Traditional preference for paddy and cotton
6. Risk aversion among small and marginal farmers.

Strategies for Promoting Crop Diversification

To effectively implement diversification, the following strategies are essential:

1. Region-Specific Crop Planning based on agro-climatic conditions
2. Assured Market Support through MSP and procurement systems

3. Strengthening Extension Services for farmer education
4. Infrastructure Development including storage and processing units
5. Promotion of Farmer Producer Organizations (FPOs)
6. Encouraging Value Addition to increase profitability
7. Research and Development for climate-resilient crop varieties.

Impact of Crop Diversification

Economic Impact:

a. Increased farm income
b. Reduced risk from market fluctuations

Ecological Impact:

a. Improved soil health
b. Conservation of water resources
c. Enhanced biodiversity

Social Impact:

a. Employment generation
b. Improved nutritional security.

Conclusion

Crop diversification is a vital pathway for sustainable agricultural development in Telangana. It addresses key challenges such as water scarcity, climate change, and economic instability. By shifting from paddy-cotton dominance to diversified cropping systems, farmers can achieve higher income, better resource management, and long-term sustainability.

A holistic approach involving policy support, technological advancements, market reforms, and farmer participation is essential to successfully implement crop diversification and transform Telangana's agriculture.

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Scope of Integrated Farming System (IFS)

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K. Sridhar[1], K. Mamatha[2], A. Sriram[2], K. Sravanti[3]
[1]AICRP on IFS, Rajendranagar
[2]Regional Agricultural Research Station, Palem,
[3]Agricultural College, Palem
Professor Jayashanakar Telangana Agricultural University, Rajendranagar.

Introduction

Integrated Farming System (IFS) is a scientific and holistic farming approach in which multiple agricultural enterprises such as crops, livestock, poultry, fisheries, horticulture, and agroforestry are systematically integrated and managed on a single farm unit. An Integrated Farming System (IFS) is a sustainable agricultural approach combining interdependent enterprises like crops, livestock, aquaculture, and agroforestry to maximize income and resource efficiency. It operates on a "zero waste" principle, where waste from one component becomes an input for another, reducing input costs and reliance on chemical fertilizers.

Unlike conventional monocropping systems, IFS focuses on synergistic interactions among components, where the output (or waste) of one enterprise becomes the input for another. This leads to enhanced productivity, reduced cost of cultivation, and improved environmental sustainability.

IFS is particularly relevant in Indian conditions, especially in semi-arid regions like Telangana, where resource constraints, climate variability, and small landholdings demand efficient and resilient farming systems.

Objectives of Integrated Farming System

The major objectives of IFS include:

1. Maximization of productivity per unit area and time
2. Efficient utilization of natural resources such as land, water, and nutrients
3. Recycling of farm wastes to reduce external inputs
4. Generation of continuous income and employment
5. Enhancement of soil fertility and ecological balance
6. Reduction of risk and uncertainty in farming
7. Improvement of livelihood security for small and marginal farmers.

Principles of IFS

IFS is based on the following guiding principles:

1. Complementarity: Each enterprise supports another (e.g., crops provide fodder, livestock provides manure).

2. Resource Recycling: Farm wastes are reused within the system, minimizing losses and external inputs.

3. Diversity: Inclusion of multiple enterprises reduces risk and enhances stability.

4. Sustainability: Maintains long-term productivity without degrading natural resources.

5. Economic Efficiency: Maximizes returns with minimum investment.

Components of Integrated Farming System

1. Crop Component: Includes cereals, pulses, oilseeds, fodder crops, and vegetables. It forms the foundation of IFS and supplies food, fodder, and residues.

2. Livestock Component: Includes dairy cattle, buffalo, sheep, and goats. Livestock provides milk, meat, manure, and acts as a source of regular income.

3. Poultry Component: Backyard poultry requires minimal investment and provides eggs, meat, and manure.

4. Fisheries Component: Fish farming in farm ponds utilizes water resources efficiently and enhances farm income.

5. Horticulture Component: Fruits, vegetables, and flowers provide high economic returns and improve nutritional security.

6. Agroforestry Component: Integration of trees with crops and livestock helps in soil conservation, carbon sequestration, and additional income.

7. Allied Enterprises: Includes beekeeping, mushroom cultivation, vermicomposting, and biogas production.

Resource Flow and Recycling in IFS

Resource recycling is the core strength of IFS, ensuring minimal wastage:

1. Crop residues → Livestock feed
2. Animal dung → Farmyard manure (FYM) or biogas
3. Biogas slurry → Organic fertilizer
4. Poultry droppings → Nutrient-rich manure
5. Fishpond water → Irrigation and nutrient supply
6. Tree leaves → Mulching material

This closed-loop system improves **nutrient use efficiency and reduces dependence on chemical inputs**.

Types and Models of IFS

1. Crop-Livestock System: Most widely practiced system where crops and animals are interdependent.

2. Crop-Fish System: Farm ponds are used for fish culture, and nutrient-rich water supports crop growth.

3. Crop-Poultry System: Poultry provides manure and additional income with minimal investment.

4. Crop-Horticulture System: Combines field crops with fruits and vegetables for higher profitability.

5. Agroforestry-Based System: Trees integrated with crops improve soil and provide long-term benefits.

6. Multi-Enterprise IFS Model: A comprehensive model integrating: Crops + Dairy + Poultry + Fishery + Horticulture + Agroforestry

This model ensures maximum productivity and sustainability.

Advantages of Integrated Farming System

1. Productivity- Farming system provides onopportunity to increase economic yield per unit area per unit time by virtue of intensification of crop and allied enterprises. Time concept by crop intensification and space concept by building up of vertical dimension through crops and allied enterprises.

2. Profitability - The system as a whole provides an opportunity to make use of produce/waste material of one enterprise as an input in another enterprise at low/no cost. Thus by reducing the cost of production the profitability and benefit cost ratio works out to be high.

3. Potentiality – Soil health, a key factor for sustainability is getting deteriorated and polluted due to faulty agricultural management practices viz., excessive use of inorganic fertilizers, pesticides, herbicides, high intensity irrigation etc. In farming system, organic supplementation through effective use of manures and waste recycling is done, thus providing an opportunity to sustain potentiality of production base for much longer time.

4. Balanced food- In farming system, diverse enterprises are involved and they produce different sources of nutrition namely proteins, carbohydrates, fats & minerals etc form the same unit land, which helps in solving the malnutrition problem prevalent among the marginal and sub-marginal farming households.

5. Environmental safety- The very nature of farming system is to make use or conserve the byproduct/waste product of one component as input in another component and use of bio-control measures for pest & disease control. These eco-friendly practices bring down the application of huge quantities of fertilizers, pesticides and herbicides, which pollute the soil water and environment to an alarming level. Whereas IFS will greatly reduces environmental pollution.

6. Income/cash flow round the year- Unlike conventional single enterprise crop activity where the income is expected only at the time of disposal of economic produce after several months depending upon the duration of the crop, the IFS enables cash flow round the year by way of sale of products from different enterprises viz., eggs from poultry, milk from dairy, fish from fisheries, silkworm cocoons from sericulture, honey from apiculture etc. This not only enhances the purchasing power of the farmer but also provides an opportunity to invest in improved technologies for enhanced production.

7. Saving energy- Availability of fossil fuel has been declining at a rapid rate leading to a situation wherein the whole world may suffer for want of fossil fuel by 2030 AD. In farming system, effective recycling of organic wastes to generate energy from biogas plants can mitigate to certain extent this energy crisis.

8. Meeting fodder crises- In IFS every inch of land area is effectively utilized. Alley cropping or growing fodder legume along the border or water courses, intensification of cropping including fodder legumes in cropping systems helps to

produce the required fodder and greatly relieve the problem of nonavailability of fodder to livestock component of the farming system.

9. Solving timber and fuel crises- The current production needs to be stepped up several-fold. Afforestation programmes besides introduction of agro-forestry component in farming system without detrimental effect on crop yield will greatly reduce deforestation, preserving our natural ecosystem.

10. Employment generation- Various farm enterprises viz., crop +livestock or any other allied enterprise in the farming system would increase labour requirement significantly and would help solve the problem of under employment. An IFS provides enough scope to employ family labour round the year.

11. Scope for establishment of agro- industries- When once the produce from different components in IFS is increased to a commercial level there will be surplus for value addition in the region leading to the establishment of agro-industries.

12. Enhancement in input use efficiency – An IFS provides good scope for resource utilization in different components leading to greater input use efficiency and benefit- cost ratio.

Role of IFS in Climate Change Mitigation and Adaptation

IFS plays a crucial role in addressing climate change:

1. Risk Diversification: Failure of one component is compensated by others
2. Carbon Sequestration: Trees and organic matter capture carbon
3. Water Conservation: Efficient use of water resources
4. Resilience: Better adaptability to droughts and extreme weather

Constraints in Adoption

1. Lack of awareness and technical knowledge
2. Initial investment requirements
3. Small and fragmented landholdings
4. Limited access to credit and markets
5. Labor management issues.

Strategies for Promotion of IFS

1. Capacity Building: Training and demonstrations
2. Financial Support: Subsidies and credit schemes
3. Research Support: Development of location-specific models
4. Market Linkages: Strengthening value chains
5. Infrastructure Development: Storage, processing, transport
6. Policy Support: Incentives for diversified farming

Conclusion

Integrated Farming System is a comprehensive, sustainable, and economically viable farming approach that addresses the challenges of modern agriculture. It ensures efficient resource utilization, income stability, and environmental conservation.

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Natural Colorants from Vegetables: Sources, Extraction, and Applications

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A. Ajay Raja[1]
[1]Research scholar, Department of Vegetable Science, Horticultural College and Research Institute, TNAU, Coimbatore, Tamil Nadu, India - 641 003.

Abstract
Natural colorants derived from vegetables have gained significant attention as safer and eco-friendly alternatives to synthetic dyes in the food industry. Increasing consumer demand for clean-label products and concerns regarding the health risks associated with artificial additives have accelerated research into plant-based pigments. Vegetables and their processing by-products serve as rich sources of bioactive pigments such as anthocyanins, carotenoids, chlorophylls, and betalains. These compounds not only impart attractive colors but also exhibit antioxidant, anti-inflammatory, and health-promoting properties. Recent advancements in extraction technologies, including enzyme-assisted, ultrasound-assisted, and microwave-assisted methods, have enhanced pigment recovery and stability. Furthermore, the utilization of vegetable waste aligns with circular economy principles by converting low-value residues into high-value natural additives. However, challenges related to pigment stability, cost-effectiveness, and regulatory approval still persist. This review highlights the sources, properties, extraction techniques, and applications of vegetable-based natural colorants in food systems.

Keywords: Natural pigments; vegetables; anthocyanins; carotenoids; betalains; chlorophyll; extraction techniques; food additives.

Introduction
Color is a critical quality attribute influencing consumer perception and acceptance of food products. Traditionally, synthetic colorants have been widely used due to their stability and low cost. However, increasing awareness regarding their potential adverse health effects has shifted focus toward natural alternatives.

Vegetables are excellent sources of natural pigments, including anthocyanins (red to blue), carotenoids (yellow to orange), chlorophylls (green), and betalains (red and yellow). These pigments are secondary metabolites that play vital roles in plant physiology, such as photosynthesis and protection against environmental stress.

In recent years, vegetable waste such as peels, pomace, and seeds has emerged as a sustainable source of natural colorants. This aligns with circular economy concepts, where waste is converted into value-added products. The present manuscript discusses the major classes of vegetable pigments, their extraction, applications, and future potential.

Major Natural Colorants from Vegetables
Anthocyanins: Anthocyanins are water-soluble pigments responsible for red, purple, and blue colors in vegetables such as red cabbage, brinjal peel, and purple carrot. They belong to the flavonoid group and exhibit strong antioxidant activity. However, anthocyanins are highly sensitive to pH, temperature, and light, which limits their industrial application. Despite this, they are widely used in beverages, dairy products, and confectionery.

Carotenoids: Carotenoids are lipid-soluble pigments producing yellow, orange, and red colors. Common sources include carrot, tomato, pumpkin, and capsicum. Important carotenoids include ß-carotene, lycopene, and lutein. These compounds are known for their provitamin A activity and antioxidant properties. However, they are susceptible to oxidation and degradation during processing.

Chlorophylls: Chlorophylls are green pigments essential for photosynthesis and are abundant in leafy vegetables such as spinach and coriander. They are relatively unstable and can degrade into pheophytin under acidic conditions, resulting in color loss. Stabilization using metal complexes has been explored to improve their usability in food products.

Betalains: Betalains are nitrogen-containing pigments found in beetroot and amaranth. They are categorized into betacyanins (red-violet) and betaxanthins (yellow-orange). Unlike anthocyanins, betalains are stable over a wider pH range, making them suitable for various food applications such as dairy products and beverages.

Extraction Techniques of Natural Colorants
Efficient extraction of pigments is crucial for their industrial application. Traditional solvent extraction methods are commonly used but have limitations such as solvent toxicity and low efficiency.

1. Conventional Extraction: Solvent extraction using ethanol, methanol, or acetone is widely practiced. However, it requires longer time and large solvent volumes.

2. Advanced Extraction Techniques: Recent advancements have introduced eco-friendly and efficient extraction methods:

a. **Ultrasound-assisted extraction (UAE):** Enhances pigment release by disrupting cell walls.
b. **Microwave-assisted extraction (MAE):** Reduces extraction time and solvent usage.
c. **Enzyme-assisted extraction (EAE):** Uses enzymes to break down cell walls and improve yield.
d. **Supercritical fluid extraction (SFE):** Uses CO_2 for efficient extraction of non-polar pigments.

These methods improve yield, reduce environmental impact, and preserve pigment stability.

Table 1: Major Vegetable-Based Natural Colorants:

Pigment Class	Color Range	Vegetable Sources	Solubility	Stability	Applications
Anthocyanins	Red-Blue	Red cabbage, brinjal peel, purple carrot	Water-soluble	Low (pH sensitive)	Beverages, dairy
Carotenoids	Yellow-Red	Carrot, tomato, pumpkin	Fat-soluble	Moderate (oxidation sensitive)	Juices, bakery
Chlorophyll	Green	Spinach, coriander	Fat-soluble	Low (heat & acid sensitive)	Sauces, processed foods
Betalains	Red-Yellow	Beetroot, amaranth	Water-soluble	Moderate (pH stable)	Ice cream, yogurt

Applications of Natural Colorants

Natural vegetable pigments are widely used in food, pharmaceutical, and cosmetic industries. In foods, they are used to enhance visual appeal and nutritional value. Anthocyanins are used in beverages and yogurts, carotenoids in dairy and bakery products, betalains in confectionery, and chlorophylls in sauces and processed foods. Additionally, these pigments provide health benefits such as antioxidant, anti-inflammatory, and anticancer properties, making them functional ingredients.

Challenges and Future Prospects

Despite their advantages, natural colorants face several challenges:

1. Poor stability under processing conditions
2. High extraction cost
3. Limited shelf life
4. Regulatory constraints

Future research should focus on improving pigment stability through encapsulation, nano-formulation, and genetic improvement of vegetable crops.

Conclusion

Natural colorants derived from vegetables represent a promising alternative to synthetic dyes due to their safety, sustainability, and health benefits. Advances in extraction technologies and waste utilization strategies have enhanced their commercial potential. However, addressing challenges related to stability and cost remains essential for their widespread adoption in the food industry.

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Carbon Credit Markets: Turning Pollution into Opportunity

Article ID: 73517

Abhilash[1]
[1]Ph.D. Scholar, College of Agriculture, University of Agricultural Sciences, Dharwad.

Summary of Article

Carbon credit markets are systems designed to reduce greenhouse gas emissions by assigning a monetary value to carbon output, where one credit permits the emission of one metric ton of carbon dioxide and can be traded among firms. Companies emitting less than their limit can sell excess credits, while those exceeding limits must buy them. These markets include compliance markets (government-regulated) and voluntary markets (optional participation), promoting cost-effective emission reduction, innovation, and global cooperation. Credits are generated through projects like renewable energy and reforestation, though concerns such as poor credit quality, greenwashing, and measurement difficulties persist. Despite these challenges, carbon markets are expected to expand with stronger regulations and improved technologies, playing a key role in achieving climate goals.

Introduction

As the world grapples with the urgent challenge of climate change, governments, businesses, and individuals are searching for innovative ways to reduce greenhouse gas emissions. Among the most talked-about solutions is the concept of *carbon credit markets*—a system that puts a price on pollution and rewards those who reduce it (IPCC, 2023; World Bank, 2024).

What are Carbon Credits?

A carbon credit represents the right to emit one metric ton of carbon dioxide (or its equivalent in other greenhouse gases). These credits are part of a broader system designed to limit overall emissions while allowing flexibility in how reductions are achieved (UNFCCC, 2022).

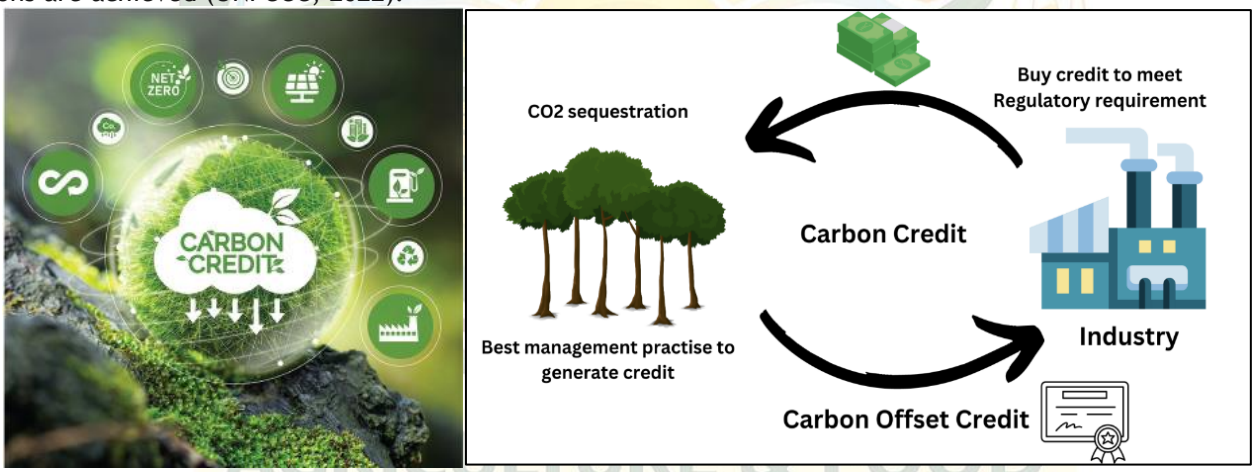


Figure: Carbon Credit Markets

Think of it like a budget for pollution. Governments or international bodies set a cap on total emissions and distribute or auction carbon credits to companies. Firms that reduce emissions below their allocated limit can sell their extra credits, while those that exceed their limits must buy additional credits or face penalties (World Bank, 2024).

How do Carbon Credit Markets Work?

Carbon markets operate on a simple principle: **polluters pay, and reducers earn**.

There are two main types of carbon markets:

1. Compliance Markets: These are regulated by governments. Companies are legally required to adhere to emission limits. Examples include cap-and-trade systems where total emissions are capped and credits are traded among firms (UNFCCC, 2022).

2. Voluntary Markets: In these markets, companies and individuals voluntarily purchase carbon credits to offset their emissions. For example, an airline might buy credits to compensate for emissions from its flights, or a corporation might aim to become "carbon neutral" (IEA, 2023).

Why Carbon Markets Matter

Carbon credit markets offer several advantages:

1. Cost-Effective Emission Reduction: Companies that can reduce emissions cheaply do so and sell credits, ensuring reductions happen where they are most efficient (Stern, 2007).

2. Incentive for Innovation: Firms invest in cleaner technologies to reduce emissions and generate tradable credits (IPCC, 2023).

3. Global Collaboration: Carbon markets allow emission reductions to occur across borders, making climate action a shared global effort (World Bank, 2024).

Real-World Applications

Carbon credits often originate from projects that reduce or remove emissions, such as:

1. Renewable energy projects (solar, wind)
2. Reforestation and afforestation
3. Methane capture from landfills
4. Energy efficiency improvements

For instance, a forest conservation project that prevents deforestation can generate carbon credits by absorbing carbon dioxide from the atmosphere (IPCC, 2023).

Challenges and Criticisms

Despite their promise, carbon credit markets are not without controversy:

1. Quality Concerns: Not all carbon credits represent real or permanent emission reductions (IEA, 2023).

2. Greenwashing: Some companies may rely on credits instead of actually reducing their emissions (Stern, 2007).

3. Measurement Difficulties: Accurately calculating emissions reductions can be complex (UNFCCC, 2022).

Ensuring transparency, credibility, and robust verification is crucial for the long-term success of these markets (World Bank, 2024).

The Future of Carbon Credit Markets

As climate policies tighten and awareness grows, carbon markets are expected to expand significantly. Advances in technology, such as blockchain and satellite monitoring, may improve tracking and verification of carbon credits (IEA, 2023).

Moreover, as countries commit to net-zero targets, carbon markets could play a central role in achieving global climate goals (IPCC, 2023).

Conclusion

Carbon credit markets represent a powerful intersection of economics and environmental policy. By assigning a cost to carbon emissions, they encourage businesses and individuals to rethink how they operate and invest in cleaner alternatives. While challenges remain, with proper regulation and transparency, carbon markets could become a cornerstone of the global fight against climate change (World Bank, 2024).

In essence, carbon credit markets transform the problem of pollution into an opportunity—where cutting emissions is not just environmentally responsible, but economically rewarding.

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Contaminants of Emerging Concern: The Microplastic Effect on Soil

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Soumyajit Chanda[1]
[1]1st year M.Sc. Soil science, Lovely Professional University, Phagwara, Delhi G.T. Road, Punjab.

Abstract
In current scenario microplastic has a severe effect on soil. We do plastic mulches for conservation of soil moisture, use sewage sludge and compost that comes from wastewater treatment plans. But these things have negative impacts also. It not only affect the plant, but also affects human body. Further this microplastic can limit the water uptake of plants which causes reduced plant growth & yield.

Introduction
Now a days plastic products are an integral part of the world economy. But poor waste disposal practices have led to serious leakage into terrestrial ecosystems. Microplastics, which are plastic particles less than five millimeters in size, have been identified as a extensive environmental pollutant. While previous studies focused mainly on marine ecosystems; there is now recognition of the potential, for serious impacts on terrestrial ecosystems (particularly in agricultural soils). Recent comprehensive studies have shown that there is a problem of plastic pollutants in agricultural soil that can affect crops, leading to a threat to food security; with up to 0.3 percent of plastics by weight in some soils. These refractory particles are now entering the lithosphere, where they are fragmented into nano plastics and permanently changing the biophysical environment in soil.(*FAO Study Warns Plastic Pollution in Soils Threatens Food Security - IKHAPP*, n.d.).

Effect of Plastic Mulching
The presence of microplastics in agricultural soils is significantly influenced by deliberate agronomic activities, which involve the use of plastic film mulching. Polyethylene film mulches are commonly applied worldwide to control soil temperatures and optimize water usage efficiency to enhance crop development. In spite of that, as a result of ultraviolet degradation, tilling activities, and improper management of waste residues; microplastic particles are directly introduced into the soil matrix. Research has shown a strong linear correlation between the duration of film application and microplastic content in soils. Specifically, extreme microplastic concentrations above 1000 pieces/kg of soil can be observed after 24 years of continuous film application.(Yu et al., 2022).

Effect of various Biosolids and Irrigation
There are other agricultural practices that are important in increasing microplastics in the soil environment. One of these is the sewage sludge and compost usage in agricultural environments. At wastewater treatment plants, massive amounts of microfibers and microbeads from personal care products are collected from wastewater. When this sludge is then used on agricultural environments to enrich the soil, hundreds of thousands of tons of microplastics are introduced into agricultural environments worldwide every year. This implies that soil enrichment with microplastics is directly proportional to the amount of sludge and compost usage.(Yu et al., 2022).

Biophysical Disturbances
The presence of microplastic particles has significant effects on the formation of water-stable aggregates, which is essential for erosion control and pore space maintenance; which basically disturb the biophysical characteristics. The different shapes and sizes of microplastic particles also have different effects on the soil; for example, microfibers such as polyester cause dose-response effects on the reduction of soil aggregation and bulk density. These alterations disrupt the critical association between the soil and water, affecting the capacity and hydraulic conductivity; which is critical for the metabolic activity and association of the entire microbial community.(De Souza MacHado et al., 2018).

Adverse effect on Invertebrates
Degradation of the biophysical environment poses an adverse impact on terrestrial biological communities, especially on invertebrates inhabiting soil environments. Earthworms are vital for nutrient cycling and soil structural stability. They experience severe physiological stress when exposed to microplastics. When exposed to conventional plastics such as polyethylene, catalase activity is increased to break down detrimental cellular hydrogen peroxide, while when exposed to biodegradable plastics, activity of the enzyme superoxide dismutase is reduced, resulting in lipid peroxidation and damage to cellular membranes. Ultimately, these particles impose severe oxidative stress on earthworms and thus impact ecosystem stability in agricultural soil environments.(*Tiny Plastics, Big Impact: How Microplastics Affect Earthworms and Soil Health – Young Investigators Review*, n.d.).

Phytotoxicity and Plant Uptake

As levels of accumulated microplastic particles rise to critical levels of phytotoxicity, agricultural production is directly affected. Large microplastic particles tend to adhere to root and create mechanical barriers that limit water and nutrient absorption in the root hair zone. On the other hand, submicron nano plastics are gaining access into root cells of plants through endocytic activity. Once inside plant cells in the epidermis and vascular tissues, plant cells tend to lose integrity and suffer damage to photosynthetic pigments and the accumulation of reactive oxygen species happens, resulting in acute oxidative stress in plant cells. Which ultimately limits plant height and crop yield.(Chen et al., 2025).

Effect on Human Health

Due to the high specific surface area and hydrophobic properties, microplastic particles are prone to the adsorption of heavy metals. It means, promote their co-migration into the terrestrial ecosystem and plant life. Bioaccumulation is also observed to follow the food web, which basically promotes continuous human dietary exposure. It also adversely affects human reproduction, digestion and respiration; creating serious health concern.(Chartres et al., 2024).

Conclusion

The widespread of microplastics in agricultural soil is a critical and irreversible threat to food security, ecosystem stability, and human health. To resolve this issue, a paradigm shift in agricultural practices is necessary to transition away from plasticulture and toward a more sustainable alternative, in addition to a strong international regulatory framework. To help facilitate this transition, the Food and Agriculture Organization of the United Nations has issued a Voluntary Code of Conduct that offers principles and actions to help governments and plastic producers implement sustainable practices and prevent the harmful, long-term consequences of plastic pollution in the global agrifood system.(*A Provisional Voluntary Code of Conduct on the Sustainable Use and Management of Plastics in Agriculture - FARM-D*, n.d.).

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Leveraging Mobile Apps for Efficient Forest Management

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Dr. Madhab Chandra Behera[1]
[1]Department of Natural Resource Management, College of Forestry, Odisha University of Agriculture and Technology, Bhubaneswar-751003.

Abstract
Mobile technology has become essential in transforming forest management. Mobile applications integrating Geographic Information Systems (GIS), remote sensing, artificial intelligence (AI), and cloud computing enables real-time data collection, monitoring and analysis, improving efficiency, accuracy, and transparency in forest management. Tools like iNaturalist, M-STrIPES, e-Eye, PARIVESH, and OFMS support inventory, biodiversity tracking, wildfire monitoring, conservation, and participatory governance. Smartphone sensors and LiDAR technology have further simplified forest biometry, while mobile platforms enhance collaboration among professionals and communities. However, limited connectivity and data security remain key challenges.

Keywords: Smart Forests, Apps for Forest, Forest management at fingertip, Real-Time Monitoring, Community Engagement.

Introduction
Forests are among the most vital terrestrial ecosystems, supporting biodiversity, delivering essential ecosystem services, and sustaining human livelihoods. Effective forest management depends on accurate real time information, efficient data collection and rapid decision making mechanism, particularly for inventory, conservation and fire management. Traditionally, forest governance relied on manual surveys, paper based records and desktop GIS systems, approaches that are labour intensive and time consuming (Ali et al., 2025). However, the widespread adoption of smartphones connected with high speed internet has initiated a shift toward a more accessible and real time approach to forest monitoring (Martell, 2015). Mobile applications (Mapps), equipped with built in GPS, high resolution cameras, sensors and internet connectivity, now enable instantaneous data collection, processing, and transmission. They also support decentralized and participatory data entry, allowing forest guards, researchers and local communities to record and share field observations in real time. Such capabilities are especially important in forest ecosystems, where timely information can help prevent illegal activities, mitigate fire risks, and strengthen biodiversity conservation strategies (Andrachuk et al., 2019). Despite growing adoption, many existing digital platforms remain fragmented and insufficiently integrated with advanced analytical tools such as artificial intelligence and real time geospatial systems.

The transformative potential of mobile applications lies in their ability to create interconnected data ecosystems that support predictive analytics, automated alerts, participatory governance, and evidence based decision making (Damasevicius et al., 2024). Integrating mobile applications with artificial intelligence and geospatial technologies can significantly enhance the efficiency, responsiveness and inclusivity of forest management by bridging the gap between field level observations with administrative processes. Features such as geotagged reporting, artificial intelligence based species recognition; offline functionality and cloud synchronization enable proactive governance through early warning systems and rapid response mechanisms (Wang et al., 2025). However, challenges such as limited digital literacy, poor network connectivity in remote areas, data privacy concerns, and financial constraints remain critical. Addressing these issues through inclusive policy frameworks is essential. This article examines the applications of mobile technologies in forest management, focusing on their role in improving monitoring accuracy, transparency, community participation, and adaptive decision making.

Principles behind Working of Mobile Apps in Forest
Mobile apps designed for use in forests works primarily on an offline-first approach, in which maps and data are stored locally on the device. Mobile GIS applications utilize the Global Positioning System (GPS), digital mapping and database connectivity to capture spatial attributes of forests, such as tree locations, boundaries and habitat types. These systems operate in both online and offline modes, allowing field workers to collect data without network access and synchronize it once connectivity is restored. Integration with remote sensing technologies and external sensors, such as LiDAR and drones, enhances the precision and accuracy of forest assessments. Furthermore, smartphones equipped with LiDAR scanners and photogrammetry techniques improve the measurement of tree attributes, including diameter at breast height (DBH), tree height and crown dimensions (Kennedy 2012).

Key Applications of Mobile Apps in Forest Management
1. Fire patrol and early detection: Forest fires are significant threats to ecosystems worldwide. Mobile apps designed for fire patrols enable teams to record hotspots, coordinate patrol routes and report incidents with precise geolocation.

These applications often integrate with mapping APIs (application programming interfaces) such as Google Maps and provide interfaces for standardized reporting, reducing the reliance on informal messaging applications that lack spatial context. For example Uttarakhand's Forest Fire app revolutionised wildfire management by delivering real-time alerts, precise GPS tracking, and predictive pre-fire analytics, enabling rapid and coordinated response to forest fires.

2. Wildlife monitoring and conservation: Mobile apps are extensively used in wildlife monitoring initiatives, both by professional researchers and citizen scientists. Platforms such as *iNaturalist*, M-STrIPES and e-Eye allow users to record biodiversity observations, identify species and share data with global databases. These apps contribute to large-scale biodiversity datasets used for ecological analysis and conservation planning. In addition to pure observation, newer systems integrate alerts for human-wildlife conflict mitigation via mobile notifications, enhancing rapid response actions by forest personnel. For example, Odisha Forest and Environment Department uses "Gaja Sanrakshana-Odisha" app that provides real-time alerts on elephant movements, helping reduce human-elephant conflict by improving communication between forest officials and local communities.

3. Participatory monitoring and community engagement: Mobile apps facilitate forest management by enabling community engagement in scientific data collection and analysis. They allow local residents to record wildlife sightings, forest threats and ecological changes using GPS-enabled tools, generating large-scale spatial and temporal data that complements official surveys. Real-time reporting of incidents, such as forest fires or elephant movements, supports rapid response and risk mitigation, while participatory monitoring empowers communities and informs data-driven management decisions. For example, the "Gaja Sanrakshana-Odisha" app provides an interface for reporting the presence of wild elephants near human habitats, enabling forest officials to take timely and appropriate measures to prevent conflict.

4. Tracking ground patrol and monitoring staff performance: Mobile applications can track patrol routes using GPS trails. Supervisors can monitor field staff movement, ensure coverage of sensitive compartments, and maintain accountability. This feature improves operational transparency and reduces chances of negligence. It also ensures systematic monitoring of protected areas. For example, the OFMS mobile app (Odisha Forest Management System) assists senior forest officials at headquarters in actively monitoring the ground patrolling activities of field staff.

5. Specialized tools and augmented reality applications: Beyond data collection and reporting, advanced mobile applications incorporate specialized tools and augmented reality (AR) to visualize forest data interactively. Apps like iNaturalist and LeafSnap enable real-time species identification, while projects like ForestAR use LiDAR and AR to visualize forest structures and wildlife movements. These technologies support citizen science, environmental education, and human–wildlife conflict mitigation by providing interactive, location-based insights directly in the field.



Figure 1 Mobile app revolutionizing day-to-day forest management

6. Reporting, documentation, and automated record generation: Mobile apps helps in reporting, documentation and record generation in forest management by enabling field staff to submit real-time, GPS-tagged observations of forest conditions, wildlife sightings, and incidents. Standardized forms and templates ensure consistent data entry, while automated compilation generates reports in PDF or spread sheet formats for monthly forest activity summaries, fire incident reports, wildlife census records and plantation survival rates. This reduces administrative workload and ensures standardized documentation.

Advantages of Mobile App Integration in Forest Management

Digitizing forest workflow through mobile apps improves efficiency, accuracy and stakeholder's engagement in day to day forest management. It significantly reduces the time from data collection to analysis, minimizing transcription errors and accelerating inventory and monitoring processes. Real-time access to field data and cloud synchronization enables forest officials to respond rapidly to emerging issues such as illegal logging, pest outbreaks, forest fires and wildlife threat. Additionally, the active participation of local communities fosters transparency, collaboration, and more effective conservation outcomes (Magnuson et al., 2024).

Technical and Operational Challenges

Although most forest management apps are designed to operate offline, limited network connectivity can still pose challenges. Real-time alerts, notifications, and coordination across teams are delayed in areas with poor connectivity, and local data must eventually be synced with central databases, causing potential lags in reporting and analysis. Integration with external sensors drones or satellite feeds also require connectivity, limiting the use of live data in remote locations. Additionally, hardware durability, battery constraints, data security, technical literacy of field staff and the need for regular maintenance and updates remain critical considerations to ensure reliable performance in diverse forest environments (Choudhury et al., 2022).

Conclusion

Mobile apps are transforming forest monitoring and management by enhancing efficiency, data accuracy and stakeholder engagement. GIS-based inventory tools, biodiversity reporting platforms and AR visualization systems address key gaps in traditional practices. Success depends on thoughtful design, inclusive participation and integration with broader environmental systems. Future developments combining AI with mobile apps could enable automated species identification, anomaly detection and predictive analytics, making these tools increasingly vital for sustainable forest governance.

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Production Technology of Elephant Foot Yam (*Amorphophallus paeoniifolius*)

Article ID: 73520

Dr. D. V. Swami[1], D.V. Vinod[2], Dr. K. Mamatha[3], Dr. V. Sivakumar[4], Dr. K. Ravindra Kumar[5]
[1]Associate Director of Research, Dr. Y S R Horticultural University, Andhra Pradesh.
[2]Research Scholar, Dr. Y S R Horticultural University, Andhra Pradesh.
[3]Principal Scientist (Horti.), Dr. Y S R Horticultural University, Andhra Pradesh.
[4]Scientist (Horti.), Dr. Y S R Horticultural University, Andhra Pradesh.
[5]Senior Scientist (Horti.), Dr. Y S R Horticultural University, Andhra Pradesh.

Abstract

Elephant foot yam is an important tropical tuber crop widely cultivated in India and Southeast Asia for its high productivity, nutritional value, and economic profitability. It is recognized as a climate-resilient crop with adaptability to diverse agro-ecological conditions and relatively low pest and disease incidence. The crop plays a crucial role in food security, livelihood generation, and sustainable agriculture, particularly in smallholder farming systems. This review comprehensively discusses the production technology of elephant foot yam, including origin, botanical characteristics, climate and soil requirements, varieties, propagation methods, land preparation, planting techniques, nutrient management, irrigation, weed control, intercropping, pest and disease management, harvesting, yield, and post-harvest handling. The review also highlights advancements in organic and conservation agriculture practices and their impact on productivity and soil health.

Introduction

Elephant foot yam (*Amorphophallus paeoniifolius*), belonging to the family Araceae, is a tropical tuber crop cultivated extensively in India and several Southeast Asian countries. It has gained prominence due to its high yield potential, adaptability to diverse agro-climatic conditions, and its importance as a food and medicinal crop. The crop is especially valued in India, where it is cultivated under both rainfed and irrigated conditions, contributing significantly to farmers' income and nutritional security. Its ability to perform well under marginal conditions and its relatively lower susceptibility to pests and diseases make it an ideal candidate for sustainable agriculture systems (Ravi et al., 2011). The growing emphasis on underutilized crops and climate-resilient agriculture has further highlighted the importance of elephant foot yam as a viable alternative to conventional crops. Its integration into cropping systems enhances productivity and resource use efficiency, making it an important component of diversified farming.

Botanical Description and Crop Characteristics

Elephant foot yam is a herbaceous perennial grown as an annual for its underground corm. The plant produces a single large compound leaf arising from a pseudostem, which resembles a small tree in appearance. The corm is the economic part and is typically large, irregularly shaped, and covered with rough skin. The crop exhibits a unique reproductive behavior, wherein a solitary inflorescence emerges either before or along with leaf development.

The crop is propagated vegetatively through corm pieces, as true seed propagation is not commercially practiced. The tuber is rich in carbohydrates, particularly starch, and contains appreciable amounts of protein, fiber, and minerals. Despite its nutritional value, the presence of calcium oxalate crystals contributes to acridity, which is reduced through proper cooking and varietal improvement (Nedunchezhiyan et al., 2011).





Climate and Soil Requirements

Elephant foot yam thrives best under tropical and subtropical climates characterized by warm temperatures and high humidity. The optimum temperature range for growth is between 25 and 35°C, and the crop requires a well-distributed rainfall pattern for proper development. It is sensitive to frost and prolonged drought conditions, which can adversely affect growth and yield. The crop performs well in a variety of soils, including sandy loam, loam, and alluvial soils, provided they are well-drained and rich in organic matter. Waterlogged conditions are detrimental as they promote corm rot and reduce yield. A soil pH range of 5.5 to 7.5 is considered ideal for optimal nutrient availability and crop performance (Ravi et al., 2011).

Varieties and Cultivars

Several improved varieties of elephant foot yam have been developed to enhance yield, reduce acridity, and improve cooking quality. Among them, varieties such as Sree Padma, Sree Athira, and Gajendra have gained widespread acceptance among farmers. These varieties exhibit superior agronomic traits, including higher yield potential, better corm size, and improved consumer preference. The development of improved varieties has significantly contributed to increased productivity and profitability, particularly under improved management practices. Selection of appropriate varieties based on local agro-climatic conditions is crucial for achieving optimal yield (Nedunchezhiyan et al., 2011).

Propagation and Planting Material

Propagation is carried out using corm pieces known as setts. Healthy and disease-free corms weighing between 500 and 1000 grams are preferred for planting, as they ensure better sprouting and vigorous growth. Larger planting material generally results in higher yields due to better initial establishment. Prior to planting, corm pieces are often treated with fungicides or biological agents to minimize the risk of soil-borne diseases. Proper selection and treatment of planting material play a critical role in ensuring healthy crop establishment and minimizing early-stage losses (Suja et al., 2010).

Land Preparation and Planting

The field is prepared by deep ploughing followed by harrowing to achieve a fine tilth. Adequate incorporation of organic matter during land preparation improves soil structure and fertility. Pits are generally prepared to facilitate proper root and corm development, and these pits are filled with a mixture of soil and organic manure. Planting is usually carried out during late winter or early summer before the onset of monsoon rains. Proper spacing is maintained to ensure adequate aeration and sunlight penetration, which are essential for optimal growth. The spacing also facilitates intercultural operations and reduces competition among plants.

Nutrient Management

Elephant foot yam is a heavy feeder and requires adequate nutrient supply for optimal growth and yield. Application of organic manures such as farmyard manure enhances soil fertility and improves microbial activity. Balanced fertilization with nitrogen, phosphorus, and potassium is essential for achieving high productivity. Integrated nutrient management practices combining organic and inorganic sources have been found to improve yield, soil health, and nutrient use efficiency. Organic farming practices, including the use of green manures and biofertilizers, have demonstrated significant improvements in both productivity and sustainability (Suja et al., 2012).

Irrigation Management

Although the crop is often grown under rainfed conditions, supplemental irrigation is beneficial during periods of moisture stress. Adequate soil moisture is essential during the initial stages of growth for proper sprouting and establishment. However, excessive irrigation should be avoided as it can lead to waterlogging and increased incidence of diseases. Efficient irrigation methods such as drip irrigation have been shown to improve water use efficiency and enhance yield by maintaining optimal soil moisture conditions throughout the growth period (Suja et al., 2012).

Weed Management

Weeds compete with the crop for nutrients, water, and light, particularly during the early stages of growth. Effective weed management is essential to ensure proper crop establishment and maximize yield. Cultural practices such as mulching and manual weeding are commonly adopted. Mulching not only suppresses weed growth but also conserves soil moisture and improves soil temperature conditions. Integration of cultural and mechanical methods provides an effective approach to weed control without adversely affecting soil health (Suja et al., 2010).

Intercropping and Cropping Systems

Elephant foot yam is highly suitable for intercropping due to its wide spacing and long duration. It is commonly intercropped with crops such as legumes, vegetables, and fruit crops. Intercropping enhances land use efficiency, improves soil fertility, and provides additional income to farmers. The inclusion of leguminous crops in intercropping

systems contributes to nitrogen fixation, thereby reducing the need for external fertilizer inputs. Such diversified cropping systems promote sustainability and resilience in agricultural production (Ravi et al., 2011).

Pest and Disease Management

Elephant foot yam is relatively less susceptible to pests and diseases compared to other tuber crops. However, certain pests such as aphids and mealybugs and diseases such as collar rot, corm rot, and mosaic virus can affect the crop. Adoption of integrated pest management strategies, including the use of healthy planting material, crop rotation, biological control agents, and need-based chemical application, is essential for minimizing crop losses. Proper drainage and sanitation practices further help in reducing disease incidence (Nedunchezhiyan et al., 2011).

Harvesting and Yield

The crop matures within 7 to 9 months after planting, depending on the variety and growing conditions. Harvesting is carried out when the foliage turns yellow and starts drying, indicating physiological maturity of the corms. Corms are carefully dug out to avoid mechanical damage. Under improved management practices, yields can range from 30 to 50 tonnes per hectare, making it one of the highest yielding tuber crops. Yield performance is influenced by factors such as variety, planting material, nutrient management, and irrigation practices (Suja et al., 2012).

Post-Harvest Handling and Storage

Post-harvest handling involves cleaning, curing, and proper storage of corms to reduce losses and maintain quality. The corms are dried under shade to remove excess moisture and prevent microbial infection. Proper ventilation during storage is essential to avoid rotting. Value addition through processing into chips, flour, and other products enhances marketability and extends shelf life. Efficient post-harvest management plays a crucial role in ensuring better returns to farmers and reducing wastage (Ravi et al., 2011).

Advances in Production Technology

Recent advancements in the production technology of elephant foot yam include the adoption of organic farming practices, conservation agriculture, and improved irrigation techniques. Organic cultivation has been shown to enhance soil quality, biodiversity, and long-term sustainability while maintaining competitive yields. Conservation agriculture practices such as minimum tillage and residue management contribute to improved soil structure and moisture retention. Additionally, the development of improved varieties with reduced acridity and higher yield potential has significantly enhanced the commercial viability of the crop (Suja et al., 2012).

Conclusion

Elephant foot yam is a highly productive and economically important tuber crop with significant potential for contributing to food security and sustainable agriculture. Its adaptability to diverse agro-climatic conditions, high yield potential, and compatibility with integrated farming systems make it an ideal crop for small and marginal farmers. Adoption of improved production technologies, including integrated nutrient management, efficient irrigation, and sustainable farming practices, can substantially enhance productivity and profitability. Future research should focus on genetic improvement, pest resistance, and value addition to fully exploit the potential of this underutilized crop.

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Metabolomics Guided Breeding for Crop Improvement

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Mini. M. L[1]

[1]Department of Biotechnology, Agricultural College and Research Institute, Tamil Nadu Agricultural University, Madurai, Tamil Nadu, India.

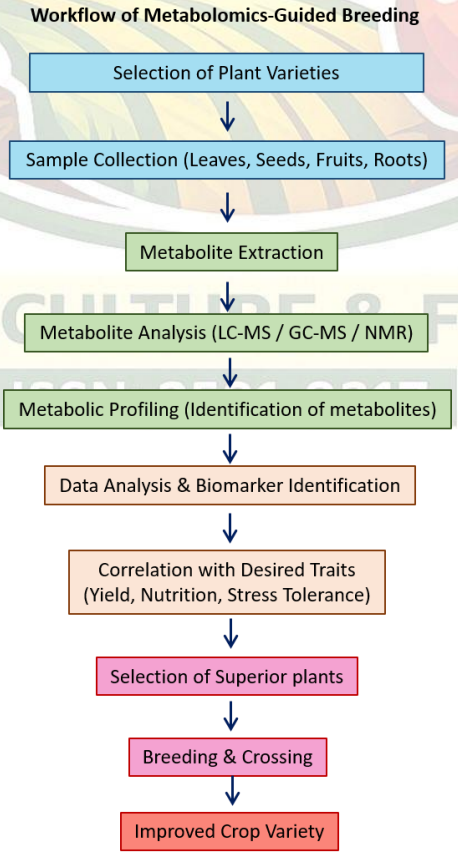
Introduction

Agriculture today faces immense challenges, including climate change, soil degradation, and the need to feed a rapidly growing global population. Traditional breeding methods, though effective, are often time-consuming and limited in their ability to precisely select desirable traits. In recent years, advances in biochemical sciences have introduced innovative strategies to improve crops more efficiently. One such promising approach is metabolomics-guided breeding, which integrates plant biochemistry with modern breeding techniques to enhance crop quality, productivity, and resilience.

Metabolomics refers to the comprehensive study of small molecules (MW < 1500 Da), known as metabolites, present within a biological system. These metabolites include sugars, amino acids, organic acids, lipids, and secondary compounds such as flavonoids and alkaloids. They are the end products of cellular processes and directly reflect the physiological state of a plant. In metabolomics-guided breeding, scientists analyze the metabolite profiles of different plant varieties to identify biochemical traits associated with desirable characteristics such as high yield, better nutritional quality, and stress tolerance. Unlike traditional breeding, which relies on observable traits (phenotypes) or genetic markers, this approach focuses on the biochemical composition of plants. Since metabolites are closely linked to gene expression and environmental interactions, they serve as reliable indicators of plant performance under various conditions.

Overview of Metabolomics Workflow

In metabolomics-guided breeding, plant samples are collected and analyzed using advanced techniques such as liquid chromatography mass-spectroscopy (LC-MS), gas chromatography-mass spectrometry (GC-MS) and nuclear magnetic resonance (NMR) spectroscopy. These techniques generate comprehensive metabolic profiles that can be compared across different plant varieties. Researchers identify specific metabolites or metabolic patterns associated with desirable traits and use them as biochemical markers in breeding programs.



Several studies highlight the value of metabolomics in plant research. It can complement traditional breeding methods such as marker-assisted selection and quantitative trait loci (QTL) mapping. These studies introduced concepts like metabolic QTLs (mQTLs) and metabolic genome-wide association studies (mGWAS), which connect metabolite variations to specific genetic regions. By integrating this information, breeders can more accurately select plants with desirable biochemical traits.

Applications of Metabolomics

One of the key advantages of metabolomics-guided breeding is its ability to improve nutritional quality, a process often referred to as "Biofortification". For example, crops can be bred to contain higher levels of essential vitamins, minerals, and antioxidants. This is particularly important in developing countries, where nutrient deficiencies are a major public health concern. By selecting plants with naturally higher concentrations of beneficial metabolites, breeders can develop varieties that contribute to better human health.

Another important application of metabolomics-guided breeding is in enhancing stress tolerance. Plants are frequently exposed to environmental stresses such as drought, salinity, and extreme temperatures. These stresses affect plant metabolism, leading to the accumulation or depletion of certain metabolites. By studying these metabolic changes, scientists can identify markers associated with stress resistance. For instance, the accumulation of osmoprotectants like proline and certain sugars is often linked to drought tolerance. By selecting plants with favourable metabolic responses, breeders can develop crops that are better adapted to challenging environments.

Metabolomics-guided breeding also plays a significant role in improving flavour, aroma, and overall quality of agricultural produce. The taste and aroma of fruits and vegetables are determined by a complex mixture of metabolites, including sugars, acids, and volatile compounds. By analyzing these metabolites, breeders can select varieties with superior sensory qualities. This has important implications for both consumer satisfaction and market value.

Metabolomics plays an important role in checking the safety of gene-edited crops because it studies all the metabolites within plant systems. It shows how gene edits can change the plant's metabolic pathways. This helps detect unexpected effects, like accumulation of toxic compounds, allergens, or changes in nutrition, which may not be predictable from genomic data alone. By comparing the metabolite profiles of gene-edited crops with regular crops, scientists can see if there are any significant differences.

Challenges

Despite its many advantages, metabolomics-guided breeding also faces certain challenges. The complexity of plant metabolism makes data analysis difficult, as thousands of metabolites may be present in a single sample. Additionally, metabolite levels can be influenced by environmental factors, making it necessary to conduct experiments under controlled conditions. The high cost of analytical instruments and the need for specialized expertise can also limit the widespread adoption of this approach, especially in resource-limited settings.

Nevertheless, ongoing advancements in technology and data analysis are making metabolomics more accessible and efficient. Integration with other "omics" approaches, such as genomics and transcriptomics, is further enhancing the power of metabolomics-guided breeding. This integrated approach allows scientists to better understand the relationship between genes, proteins, and metabolites, leading to more precise and targeted crop improvement strategies.

Conclusion

In conclusion, metabolomics-guided breeding represents a cutting-edge biochemical strategy for crop improvement. By focusing on the biochemical composition of plants, it provides a direct link between genetic information and observable traits. Numerous research studies have demonstrated its effectiveness in improving nutritional quality, stress tolerance, and crop productivity. Although challenges remain, continued advancements in analytical techniques and data integration are expected to further enhance its application. As global food demands continue to rise, metabolomics-guided breeding will play a crucial role in developing sustainable and high-performing crop varieties for the future.

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Exploring the Nutritional and Ethnobotanical Significance of *Docynia indica* in Northeast India

Article ID: 73522

Varun Athokpam[1], Themmeichon Chamroy[1]
[1]Dept of Horticulture, School of Agriculture, Lovely Professional University, Punjab, 144411.

Summary
Docynia indica, commonly known as the Assam Apple or Wild apple, is a neglected and underutilised species from the Rosaceae family. It occurs mainly in Northeast India and the Eastern Himalayas. Local communities have valued it not just as food but also for medicine and culture for centuries. The fruit is rich in vitamins, minerals, and other bioactive compound; hence it has a high potential of serving as a functional food. Despite its ethnic importance, the species remains unexplored and not yet studied sufficiently, and is endangered by deforestation, urbanization, and climate change.

Introduction
Northeast India is recognized as a rich biodiversity hotspot, abundant in various horticultural species that are largely underutilised and/or unexplored. Among these, *Docynia indica*, is one such high value wild edible fruit distributed across the states of Assam, Meghalaya, Arunachal Pradesh, Manipur and other hilly regions. It is a temperate and subtropical plant with a major impact in the food systems locally.

The fruit has received some interest due to nutritional, medicinal and economic significance among the indigenous people and its adaptability to live in marginal environments. Different communities have been using the therapeutic ability and its food value as a measure of its ethnobotanical value (Dutta *et al.*, 2025) although it has certain limitations since there is limited scientific research on them and they are not extensively commercialized thus limiting its overall use.

Taxonomy and Botany
Docynia indica belongs to the genus *Docynia*, though taxonomists have debated its classification, sometimes linking it to *Malus* (apples) or *Cydonia* (quinces). The tree grows up about 3 to 10 meters in height, and bears serrated leaves and clusters of whitish or pinkish blossoms. The fruits are small pomes, which are yellow to green, about 1.5 to 4 cm wide, edible and nutritious.



It thrives in moist soils at 1000–3000 meters elevations, especially across the eastern Himalayas, Indo-China, and southern China. Ecologically, it supports wildlife by providing food and aiding seed dispersal and contributes to nutrient cycling within the forest ecosystem.

Ethnobotany and Cultural Role

In Northeast India, it is known by many names, in Manipur "Heitup" among the Meiteis, Tangkhuls call it "Theithukthei", "Nphakthai" by the Rongmeis; in Meghalaya, the Khasis called it as "Sohphoh-khasi"; the Angamis of Nagaland locally call it "Chiepho"; "Mel" in Sikkim. For indigenous groups in Northeast India, *Docynia indica* is more than a fruit, it holds a notable place in various traditional practices. All the plant parts such as roots, leaves, flowers, and fruits are traditionally used. The teas made of leaves and shoots are used in the treatment of digestion, obesity, and diabetes (Biswas *et al.*, 2022; Shende *et al.*, 2016). Fruits are used for treating headaches, stomach aches, asthma, and arthritis (Shende *et al.*, 2016).

Nutrition and Health

Proximate analysis of *Docynia indica* indicates that per 100 g, it contains about 85% moisture, 62 kcal energy, 200+ mg potassium, and nearly 15 mg Vitamin C (Rymbai *et al.*, 2016). It also contains fiber and antioxidants like flavonoids and polyphenols. These compounds help fight oxidative stress, reduce inflammation, and support immunity.

Traditionally, people use it to manage diabetes, hypertension, digestive problems, and mild infections. Modern studies confirm antimicrobial properties, and some key bioactive constituents such as flavonoids, alkaloids, and phenolic compounds, known for having antioxidant capacity and health properties (Rymbai *et al.*, 2016; Sharma *et al.*, 2018), suggesting it could be developed as a functional food.

Value Addition and Economics

Docynia indica is not just some underexploited wild fruit but it can be profitable. A mature tree can yield up to Rs. 12,000 per annum, with the fruits being sold at Rs. 60–150 per kg (Rymbai *et al.*, 2016; Shende *et al.*, 2016). Farmers can generate income by making value-added products like jams, juices, dried fruits, pickles etc. Diced sweet heitup, heitup candies, as well as atingba, a local fermented beverage, are some renowned value-added products of *Docynia indica* in Manipur.

However, the commercialization is hindered by challenges, an early harvest, theft, and rivalry among farmers reduce the profits. The sustainable practices like integration of *Docynia* in the agro forestry can help. Not only do these trees protect soil, conserve water but they are food and medicinal trees hence making them ideal for the rural livelihood.

Conservation Challenges

Despite its potential, *Docynia indica* is under threat in their native ranges. Threats such as habitat loss due to deforestation, urbanization, and climate change are shrinking the ecosystems where the species thrives. Conservation is not only required to protect biodiversity but it is also required to protect its ability to add to the local economies and traditions. Forest habitats and genetic resources are also worth protecting (Biswas *et al.*, 2022).

Agroforestry and community-based conservation would assist in reducing poverty while protecting the ecosystems (Zhang *et al.*, 2018). By combining traditional knowledge with modern techniques, this species can be domesticated and promoted in markets without losing its ecological balance.

Conclusion

Docynia indica is more than just a wild fruit, but it is a plant that displays tradition, nutrition, and economy. For Northeast India, it represents food security, cultural heritage, and sustainable livelihoods. But without conservation, its future is at risk. Preserving and promoting this underutilized species could improve health and nutrition, and support rural incomes—all while keeping alive the cultural identity of the communities that cherish it.

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Advance in Coconut Processing and Value Addition: Varietal Importance and Future Prospects

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Km Anisha Singh[1]

[1]Research Scholar, Department of Food Science and Post Harvest Technology, Bihar Agricultural University, Sabour, Bhagalpur, 813210.

Abstract

Coconut *(Cocos nucifera)* is a highly valuable plantation crop known for its diverse applications in food, health, and industrial sectors. The coconut nut serves as a primary source for a wide range of products including copra, coconut oil, desiccated coconut, coconut chips, and virgin coconut oil. Recent advancements in processing technologies have significantly improved product quality, efficiency, and sustainability. This article highlights the importance of coconut nut, detailed processing of its products, and modern advancements in coconut processing.

Keywords: Coconut nut, value addition, advanced processing, virgin coconut oil, desiccated coconut, coconut waste utilization.

Introduction

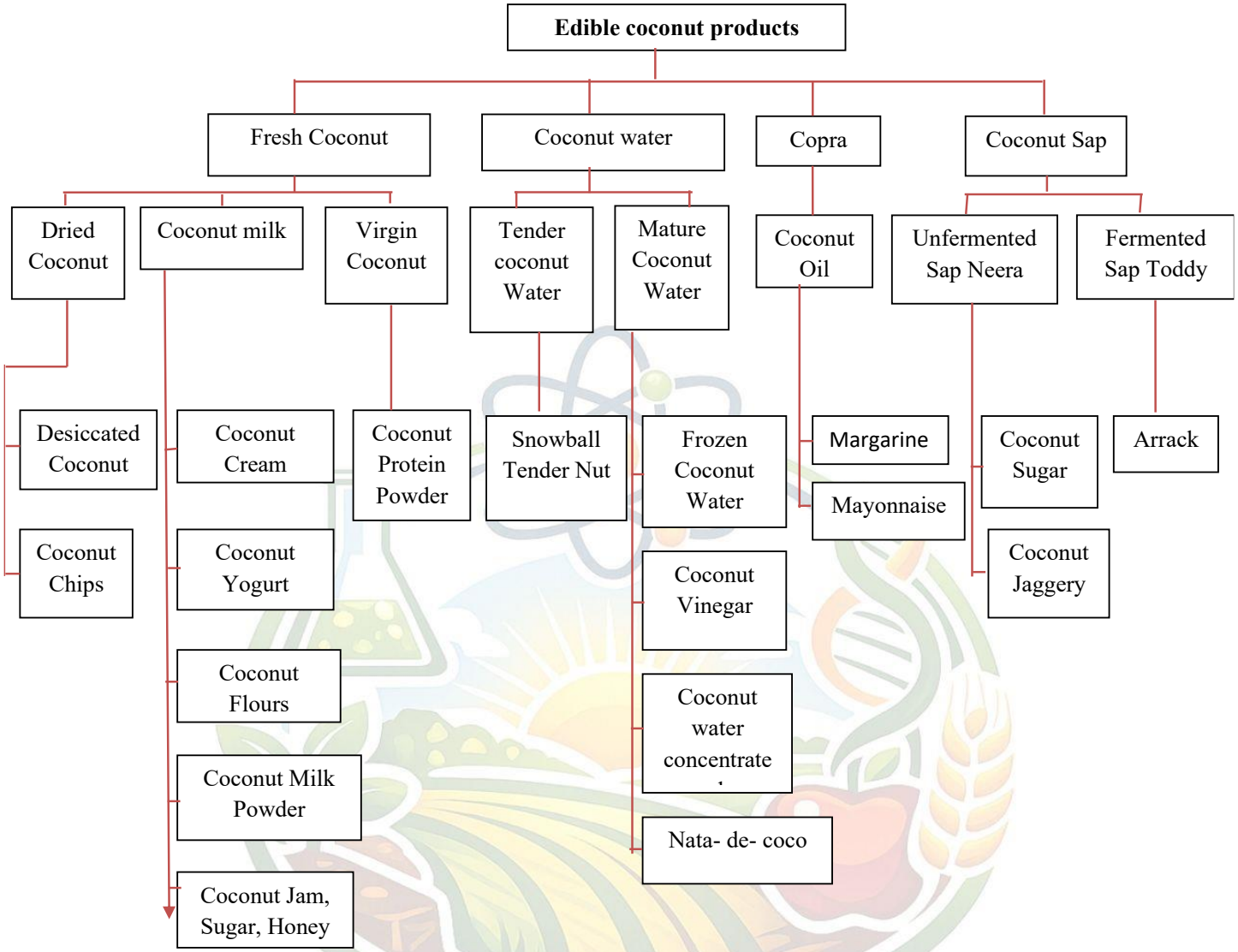
Coconut is popularly known as the "Tree of Life" because of its multiple uses. The coconut nut is particularly important as it provides edible products, industrial raw materials, and health-promoting compounds. With increasing global demand for natural and functional foods, coconut processing has emerged as a key agro-industrial sector.

Importance of Coconut Nut

The coconut nut holds great importance in several aspects:

1. **Economic Importance:**
    a. Major source of income for farmers in tropical regions
    b. Significant contribution to export and trade
    c. Supports agro-based industries
2. **Nutritional Importance:**
    a. Rich in healthy fats, especially medium-chain fatty acids
    b. Provides energy and essential nutrients
    c. Used in various traditional and modern food products
3. **Industrial Importance:**
    a. Raw material for oil, food, cosmetics, and pharmaceuticals
    b. Used in production of activated carbon and adsorbents
4. **Environmental Importance:**
    a. Promotes zero-waste utilization
    b. Coconut waste is converted into useful by-products
    c. Eco-friendly and sustainable resource.

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Coconut Nut Products and Processings

1. Primary Products:

Copra: Copra is the dried kernel of coconut and serves as the primary raw material for oil extraction. Mature coconut → Dehusking → Deshelling → Kernel removal → Drying (sun drying or mechanical drying) → Copra

Coconut Oil: Coconut oil is obtained from copra and is widely used for cooking and industrial purposes. Copra → Grinding → Oil extraction (expeller or solvent extraction)→ Filtration → Coconut oil

RBD Coconut Oil (Refined bleached deodorized): RBD oil is processed coconut oil with improved clarity, taste and shelf life. Crude oil → Degumming → Neutralization →Bleaching → Deodorization → RBD oil.

2. Value-Added Products:

Desiccated Coconut: Desiccated coconut is finely grated, dried coconut kernel used in confectionery and bakery products. Fresh coconut → Deshelling → Paring → Washing → Blanching → Shredding → Drying → Packaging.

Coconut Chips: Coconut chips are ready-to-eat snack products prepared from sliced coconut kernel. Coconut → Slicing → Blanching → Drying → Flavoring → Packaging.

Coconut Milk Coconut milk is a white emulsion extracted from fresh coconut kernel and used as a base for several products. Kernel → Grinding → Pressing → Filtration → Coconut milk.

3. Virgin Coconut Oil (VCO) Virgin coconut oil is a high-value product known for its nutritional and therapeutic properties:

a. Hot Process: Kernel → Milk extraction → Heating → Oil separation → Filtration

b. Fermentation Process: Milk → Addition of lactic acid bacteria → Fermentation → Oil separation

c. Enzymatic Process: Milk → Enzyme addition → Emulsion breakdown → Oil separation

Nutraceutical and Health Applications: Virgin coconut oil is widely recognized for its health benefits. It contains medium-chain fatty acids and exhibits anti-inflammatory properties. Studies have indicated its role in reducing C-reactive protein levels, making it valuable in therapeutic nutrition.

4. **By-products and Waste Utilization:**
   - **a. Carbonaceous Adsorbent: Coconut shell and other residues are converted into carbon-rich materials.** Coconut waste → Carbonization → Activation → Adsorbent.
   - **b. Heavy Metal Adsorbent: Processed coconut waste is used to remove heavy metals such as copper (Cu) and nickel (Ni) from wastewater.** Treated coconut waste → Used for removal of Cu and Ni from water.

Advanced Processing Techniques

Recent advancements in coconut processing have improved efficiency and product quality:

1. **Improved Drying Techniques:**
   - a. Use of mechanical dryers instead of traditional sun drying
   - b. Better moisture control and hygiene
2. **Modern Oil Extraction Methods:**
   - a. Cold pressing and controlled heating
   - b. Higher oil recovery and improved quality
3. **Fermentation Technology:**
   - a. Use of selected lactic acid bacteria for VCO production
   - b. Enhanced purity and nutritional value
4. **Enzymatic Extraction:**
   - a. Use of enzymes to break coconut milk emulsion
   - b. Increased oil yield and efficiency
5. **Waste Utilization Technology:**
   - a. Conversion of coconut waste into activated carbon
   - b. Application of water purification and environmental protection
6. **Quality Control and Storage:**
   - a. Refining (RBD process) improves shelf life
   - b. Better packaging and storage systems.

Machinery Used in Advanced Processing

1. Dehusker and desheller
2. Paring machine
3. Mechanical dryers
4. Oil expellers and filter presses
5. Fermentation tanks
6. Enzymatic reactors

These machines improve efficiency, ensure product quality, and reduce manual labor.

Economic and Future Prospects

Coconut processing offers great potential for:

1. Value addition and income generation
2. Export growth
3. Development of health-based products
4. Sustainable industrial applications.

Future Aspects of Coconut Processing

1. Increasing demand for value-added products such as virgin coconut oil, desiccated coconut, and coconut chips.
2. Growing importance of nutraceutical uses, especially the therapeutic potential of virgin coconut oil.
3. Adoption of advanced processing techniques like enzymatic extraction, fermentation, and improved drying methods.
4. Better waste utilization, converting coconut residues into activated carbon and adsorbents for environmental applications.
5. Expansion of export opportunities due to rising global demand for natural and plant-based products.
6. Continued research and innovation for improving product quality, efficiency, and development of new coconut-based products.

Coconut Varieties

1. Tender nut water: Chowghat Orange Dwarf, Chowghat Green Dwarf, Malayan Orange Dwarf, Malayan Green Dwarf, Java, Kalpa Raksha, Gangabondam,

Kenthali Orange Dwarf – Has high medicinal value in its tender nut water
Kalpa Sreshta – Hybrid suited for tender nut purposes
Kalpa Sree – Very sweet tender nut water
Kalpa Jyothi – Dwarf yellow nut variety, recommended for tender nut purposes
Kalpa Surya – Dwarf orange nut variety, recommended for tender nut purposes

2. For tapping toddy:

Lakshadweep ordinary (Chandra kalpa) – Excellent for toddy tapping
Cochin China – Good toddy yielder
Coconino – Good for tapping

3. For ball copra: Laccadive micro, Kalpa Tharu.

Summary

Coconut nut processing is a comprehensive and sustainable system that utilizes every part of the nut efficiently. The integration of advanced technologies with traditional methods has significantly enhanced the scope and profitability of coconut-based industries. With growing demand and innovation, coconut processing will continue to play a vital role in economic development and environmental sustainability.

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Pearl Millet: An Eco-Friendly Alternative to Health, Food Security, and Sustainable Approach to Environmental Resilience

Article ID: 73524

Kajal Nagre[1], Nirupma Singh[2]

[1]Department of Genetics and Plant Breeding, Shree Guru Gobind Singh Tricentenary University, Gurugram-122505.

[2]Division of Genetics, ICAR-IARI, Pusa, New Delhi-110012.

Abstract

Pearl millet (*Pennisetum glaucum*) as a crop that directly contributes to several Sustainable Development Goals (SDGs) of the UN and is climate – resilient, nutritionally dense, and environmentally sustainable. One of pearl millet's most notable qualities is its high nutritional content, which makes it an important part of human diets in area with few options for staple foods. It is a valuable food source because of its nutritional composition, particularly for areas where it is major food staple. Pearl millet is just as important for animal production as it is for human use. Animals can benefit greatly from the fresh or dried straw of the pearl millet. Pearl millet thrives in arid and semi-arid regions with minimal inputs, making it a life line for small holder farmers and a strategic solution to SDG 2 (Zero hunger), SDG 3 (Good Health and well being), SDG 12 (Responsible consumption and production), SDG 13 (climate action).

Keywords: Environmental sustainability, Sustainable Developmental Goals, Climate action, Nutrition.

Introduction

Food security, nutrition, and environmental sustainability face currently unfathomable difficulties in the twenty- first century. A global crisis is being created by the combination of population expansions, resources shortage, and climate change. In 2023, more than 2 billion individuals experienced micronutrient deficiencies, and over 735 million people went hungry according to the FAO. Climate change affects and is influenced by food systems, as agriculture accounts for around one- third of global green house gas emissions. In light of this, efforts to find crops that are nutrient- dense, climate- resilient and environmentally sustainable have accelerated (Al-Khaleel *et al*; 2025). In order to draw attention to millets' contribution to sustainable food systems, the UN designated 2023 as the International Year of Millets. As a world leader in millet production, India has incorporated millets into nutrition campaigns, school feeding programs, and public distribution networks. As part of measures for climate adaptation, international organizations like the FAO and ICRISAT are encouraging the production and consumption of millet (Nimmy *et al*; 2024, Perumal *et al*; 2024).

Pearl millet is unique among crops that can concurrently promote food security (SDG 2), health and well- being (SDG 3), responsible consumption and production (SDG 12), climate action (SDG 13) in the context of the UN sustainable Development Goals (SDGs). The article explores how pearl millet incorporates cutting- edge science, supports several SDGs, and offers sustainable answers to global issues.

Pearl Millet and SDG 2: Zero Hunger

An essential crop for reaching SDG 2: Zero Hunger is pearl millet (*Pennisetum glaucum*), especially in dry and semi-arid areas of Asia and Africa. When other grains fail, its resistance to heat, drought, and poor soils guarantees food availability. Pearl millet is essential for smallholder farmers since it grows with little water and nutrients, unlike rice and wheat, which require large amounts of these inputs. Iron, zinc, magnesium, and critical amino acids are all abundant in pearl millet. These qualities directly address hidden hunger, a state in which adequate calorie intake is accompanied by persistent nutritional deficits (Satyavathi *et al*; 2021). Research shows that it prevents stunting and anemia in children and women who are of reproductive age (Al-Khaleel *et al*; 2025).

Pearl Millet and SDG 3: Good Health and Well-Being

The pearl millet provides functional nutrition and lessens the burden of non-communicable diseases, it directly advances SDG 3: Good Health and Well-Being. It is appropriate for diabetic diets because of its high dietary fiber content, which decreases cholesterol and enhances glycemic management.

Antioxidants and photochemical further lower the risk of obesity and cardiovascular disease (Srivastava *et al*; 2022). Programs for biofortification have proven essential in improving the nutritional profile of pearl millet. Varieties with up to 70% more iron and zinc have been created using genomic-assisted breeding (Govindaraj *et al*; 2019).

Additionally, pearl millet promotes the health of mothers and children. Its slow-digesting carbohydrate gives kids long-lasting energy, and its gluten-free status makes it appropriate for people with celiac disease (Govindaraj *et al*; 2019).

Pearl Millet and SDG 12: Responsible Consumption and Production

Pearl millet encourages environmentally friendly inventions and sustainable farming methods, which advances SDG 12: Responsible Consumption and Production. Compared to rice and wheat, its cultivation uses a lot less water and chemicals, which lessens its environmental impact. Additionally, pearl millet planting supports circular economies. Waste is reduced by using by-products like husks and bran for composting, animal feed, and biofuel. Crucially, pearl millet starch is becoming a popular raw source for plastics that decompose naturally.

1. Millet Starch as a Biodegradable Alternative to Plastic: Studies reveal that pearl millet starch can be converted into films and packaging materials, providing substitutes for plastics made from petroleum. These bioplastics comply with international limits on single-use plastics since they are non-toxic, renewable, and biodegradable. Work on pearl millet starch films from Indian varieties (such as HHB 67 and ProAgro 9444) reports that extracted starch can form continuous, flexible films suitable for developing biodegradable packaging, especially when blended with plasticizers like glycerol (Dhillon *et al*; 2022). Studies on physical modification (e.g., heat-moisture treatment, microwave treatment) of pearl millet starch show that the modified starch can be used to cast films with improved moisture resistance, transparency, and solubility, supporting its use in biodegradable packaging (Shaikh *et al*; 2019).

2. Active and reinforced films: In order to increase shelf life and lessen dependency on artificial preservatives, cross-linked pearl millet starch films loaded with fenugreek oil have been created as "active" edible films with antibacterial and antioxidant qualities (Dhull *et al*; 2021). Pearl millet starch and cellulose nanocrystals derived from kudzu (and occasionally clove bud oil) are combined to create nanocomposite films that exhibit improved mechanical strength, water barrier qualities, and antimicrobial activity. These films have been tested for short-term fruit packaging, including grapes (Bangar *et al*; 2022).

Table 1: Pearl millet starch comparison with conventional plastic:

Sr. No.	Feature	Pearl Millet Starch	Conventional Plastic
1.	Biodegradability	Fully biodegradable	Non-biodegradable
2.	Raw Material	Renewable (crop-based)	Petroleum-based
3.	Environmental Impact	Low carbon footprint	High carbon footprint
4.	Health Safety	Non-toxic	Harmful additives possible

Pearl Millet and SDG 13: Climate Action

Pearl millet is a climate-smart crop that promotes climate action. Because it can withstand high temperatures and erratic rainfall, it is a reliable option in climate stress. Unlike shallow-rooted grains, pearl millet has a deep root system that enhances soil structure, promotes water retention, and helps sequester carbon (Satyavathi *et al*; 2021). In arid and semi-arid locations, pearl millet lowers crop failure and stabilizes smallholder incomes since it is more drought and heat resistant than rice, wheat, or maize and produces better under high temperatures and unpredictable rains. By reducing reliance on crops like wheat and rice that are susceptible to climate change, using pearl millet to diversify agricultural systems increases resilience. (https://www.icrisat.org/crops/pearl-millet/overview).

Climate action is advanced by the climate- smart crop pearl millet. It is a dependable choice in climate stress due to its resistance to high temperatures and unpredictable rainfall. The deep root system of pearl millet, in contrast to shallo0w-rooted grains, improves soil structure, increases water retention, and aids in carbon sequestration (Satyavathi *et al*; 2021). Pearl millet is highly drought and heat tolerant, yielding better than rice, wheat, or maize under high temperatures and erratic rainfall, which reduces crop failure and stabilizes small holder incomes in arid and semi arid regions. Using pearl millet to diversify agricultural systems strengthens resilience by lowering dependency on crops like wheat and rice that are vulnerable to climate change (https://www.icrisat.org/crops/pearl-millet/overview).

Summary

Pearl millet is an excellent example of how agriculture, nutrition, and environmental sustainability are intertwined. Pearl millet directly supports a number of SDGs by combating hunger and malnutrition, advancing health, lessening environmental impact, and providing b biodegradable plastic substitutes. Its potential further enhanced by multi omics technologies, which make it key component of future food systems. Pearl millet offers a comprehensive solution as the globe struggles with resource shortages, plastic pollution, and climate change it feeds people, promotes health, and heals the planet. Adoption is a calculated investment in a sustainable future as well as an agriculture decision.

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Role of Transplastidomic Technology in Plant Breeding

Article ID: 73525

Kumari Rekha[1], Prity Sundaram[2], Satish Kumar[3]
[1,2]Assistant Professor-cum-Junior Scientist
[3]Associate Professor-cum-Senior Scientist
[1,3]Mandan Bharti Agriculture College, Bihar Agricultural University, Sabour, Bhagalpur.
[2]Bhola Paswan Shastri Agricultural College, Bihar Agricultural University, Sabour, Bhagalpur.

Summary

Transplastidomic technology involves the introduction of foreign genes into the chloroplast (plastid) genome rather than the nuclear genome. This approach plays a significant role in crop improvement due to its high efficiency and biosafety advantages. It enables high-level and stable expression of transgenes because chloroplasts contain multiple copies of their genome. The technology also allows multigene engineering, making it possible to modify entire metabolic pathways for enhanced nutritional quality and productivity. An important advantage is maternal inheritance, which limits transgene transmission through pollen and reduces the risk of gene flow to wild relatives. Transplastidomic crops can be developed with improved resistance to pests, diseases, drought, and salinity, as well as enhanced photosynthetic efficiency and yield. Overall, transplastidomic technology is a powerful and safe tool for developing high-yielding, stress-tolerant, and nutritionally improved crops.

Introduction

Transplastidomic plants are genetically engineered plants in which foreign genes are inserted into the plastid genome (chloroplast DNA) instead of the nuclear genome. This technology plays an important role in modern plant breeding and crop improvement.

1. High-Level Gene Expression:
- a. Chloroplasts contain multiple genome copies per cell.
- b. Foreign genes inserted into plastids can produce very high levels of proteins.
- c. Useful for producing:
  - i. Insecticidal proteins (e.g., Bt toxins)
  - ii. Industrial enzymes
  - iii. Vaccine antigens
  - iv. Biopharmaceuticals

2. Maternal Inheritance (Gene Containment):
- a. In most crops, plastids are inherited maternally (through the egg cell).
- b. Transgenes in chloroplasts are generally not transmitted via pollen.
- c. Reduces risk of gene flow to wild relatives.
- d. Important for biosafety in plant breeding.

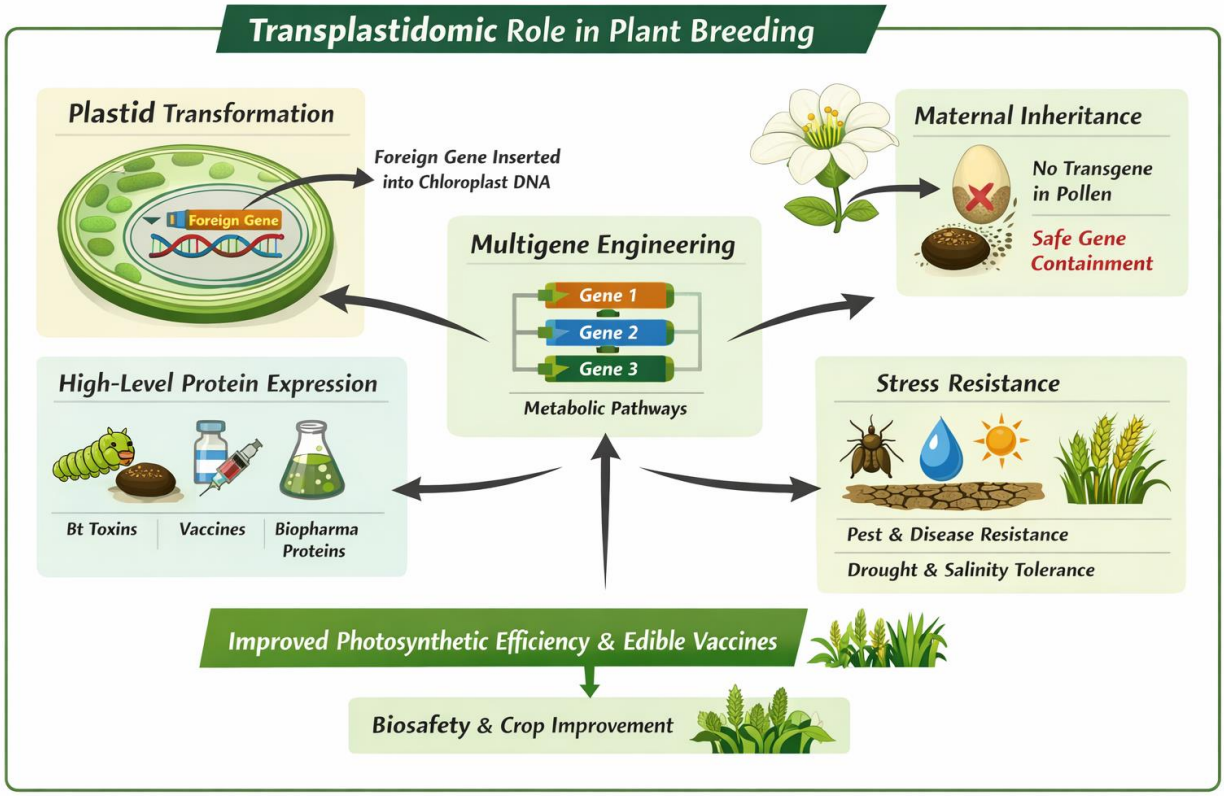
3. Multigene Engineering:
- a. Chloroplast genome allows insertion of multiple genes in a single transformation event.
- b. Entire metabolic pathways can be engineered.
- c. Useful for:
  - i. Biofortification (e.g., vitamin-enriched crops)
  - ii. Improved nutritional quality

4. Enhanced Resistance to Biotic and Abiotic Stresses:
- a. Development of resistance against:
  - i. Insect pests
  - ii. Fungal and bacterial diseases
  - iii. Viral infections
- b. Improved tolerance to:
  - i. Drought
  - ii. Salinity
  - iii. Temperature stress

5. Avoidance of Gene Silencing and Position Effect:
- a. Transgenes integrate at specific sites via homologous recombination.
- b. No position effect (unlike nuclear transformation).
- c. Stable and predictable gene expression.

d. Reduced transgene silencing.

6. **Improved Photosynthetic Efficiency:** Since chloroplasts are the site of photosynthesis, engineering plastid genes can:
   a. Improve carbon fixation
   b. Increase biomass production
   c. Enhance crop yield
7. **Production of Edible Vaccines:**
   a. Transplastidomic plants can produce vaccine proteins in edible tissues.
   b. Offers low-cost vaccine production systems.



Limitations

1. Efficient plastid transformation protocols are available mainly for a few crops (e.g., tobacco).
2. Regeneration of transformed plants can be difficult in many species.
3. Limited success in major cereals like rice and wheat.

Conclusion

Transplastidomic technology is a powerful tool in plant breeding that enables high-level, stable, and safe expression of foreign genes. It contributes to crop improvement through enhanced resistance, improved nutritional quality, and biopharmaceutical production, with reduced environmental risk due to maternal inheritance.

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Chia Seeds: Functional Superfood for Modern Nutrition

Article ID: 73526

Dr. Poorva Dashora[1]
[1]Assistant Professor (Home Science), Government College, Bassi, Chittorgarh, Rajasthan (312022).

Abstract
In the present era of nutritional insecurity and increasing lifestyle-related disorders, chia seeds (*Salvia hispanica L.*) have emerged as a highly promising functional food. These seeds are gluten-free and rich in omega-3 fatty acids, dietary fiber, protein, antioxidants, vitamins, and minerals. Due to their exceptional nutritional profile and health-promoting properties, chia seeds are gaining global recognition as an important dietary component. They play a significant role in preventing lifestyle diseases and improving overall health.

Introduction
Chia (*Salvia hispanica L.*) is an ancient crop belonging to the family Lamiaceae and is native to Central America. It was widely used by Aztec and Mayan civilizations as a staple food and energy source. Chia seeds are small, oval, and highly hydrophilic, capable of absorbing several times their weight in water to form a gel-like structure. Owing to their superior nutritional value and functional properties, they are now widely recognized as a "superfood" in modern diets.



Nutritional Composition of Chia Seeds
Chia seeds possess a remarkable nutrient profile. They contain high-quality protein (15–20%) with essential amino acids. They are particularly rich in dietary fibre (30–40%) and omega-3 fatty acids (alpha-linolenic acid). Additionally, chia seeds provide vitamins such as B-complex and vitamin E, along with essential minerals like calcium, iron, magnesium, phosphorus, and potassium. They are also rich in bioactive compounds including flavonoids and phenolic antioxidants.

Health Benefits of Chia Seeds
Chia seeds offer numerous health benefits. They help reduce cholesterol levels and improve cardiovascular health. Their high fibre content aids digestion and promotes gut health. Chia seeds also assist in regulating blood glucose levels, making them beneficial for diabetic patients. Due to their high satiety value, they support weight management. Furthermore, their antioxidant and anti-inflammatory properties contribute to overall wellness and disease prevention.

Agronomic Importance
Chia is a short-duration crop that performs well under diverse agro-climatic conditions. It shows tolerance to drought and can be cultivated in semi-arid regions with minimal inputs. The crop can be integrated into sustainable farming systems and has potential for diversification in Indian agriculture, especially under changing climate scenarios.

Processing and Utilization

Chia seeds can be consumed in both raw and processed forms. Common processing methods include soaking, grinding, roasting, and incorporation into food products. They are widely used in smoothies, beverages, bakery products, breakfast cereals, salads, and nutritional supplements. The gel-forming ability of chia seeds also makes them useful as a thickening and stabilizing agent in food formulations.

Conclusion

Chia seeds are a highly nutritious and versatile functional food with great potential to enhance human health and nutrition. Their rich composition of essential nutrients and bioactive compounds makes them suitable for combating malnutrition and lifestyle diseases. Promotion of chia cultivation and consumption can contribute to improved food security and sustainable agriculture.

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Balanced Diet: A Foundation for Healthy Living

Article ID: 73527

Dr. Poorva Dashora[1]
[1]Assistant Professor (Home Science), Government College, Bassi, Chittorgarh, Rajasthan (312022).

Abstract
A balanced diet is essential for maintaining good health, proper growth, and overall well-being. It provides all the necessary nutrients in appropriate proportions required by the body for normal functioning. In the modern era of fast-food consumption and sedentary lifestyles, maintaining a balanced diet has become increasingly important to prevent nutritional deficiencies and lifestyle-related diseases. This article highlights the importance, components, and benefits of a balanced diet.

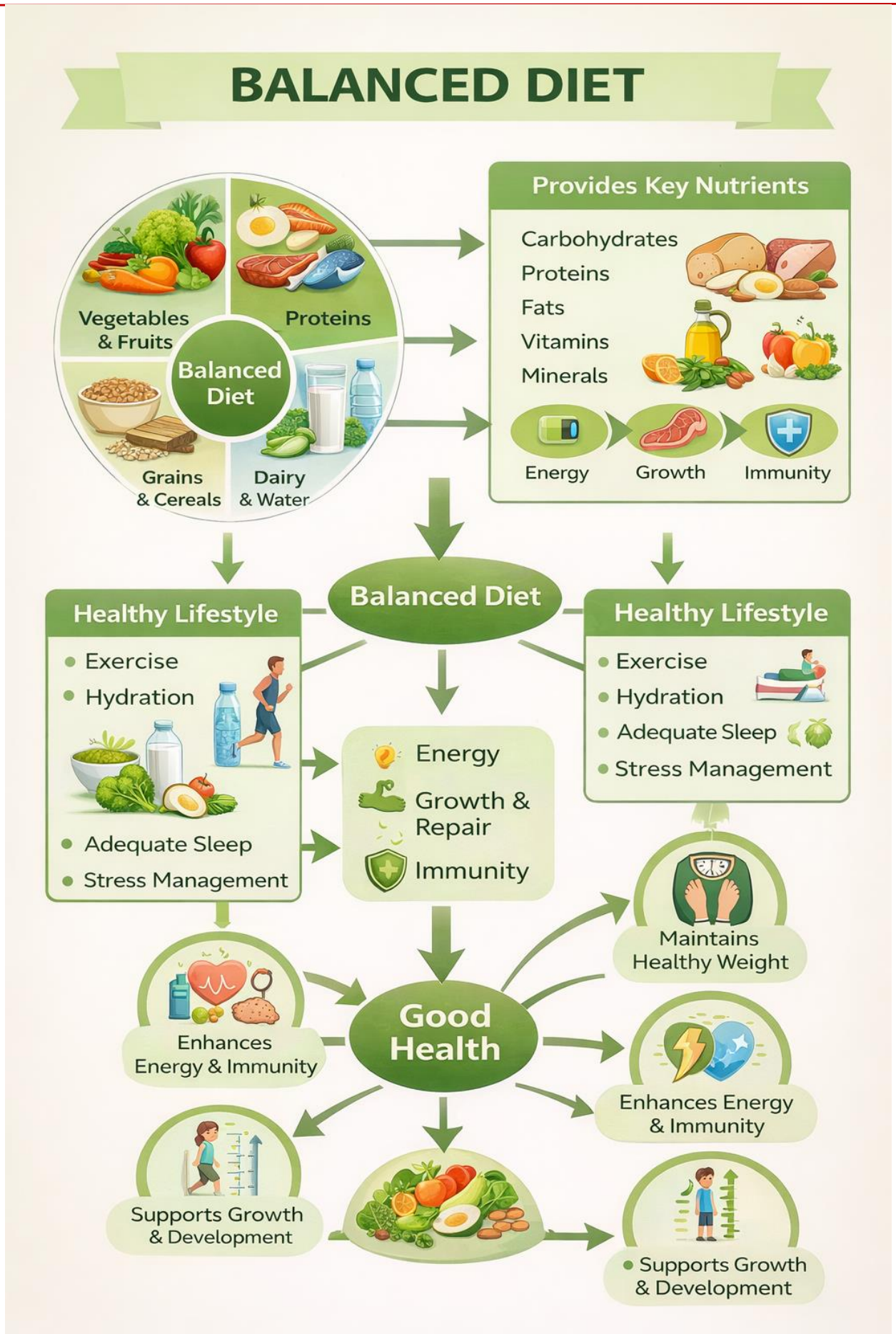
Introduction
A balanced diet refers to the consumption of a variety of foods in the right proportions to provide essential nutrients such as carbohydrates, proteins, fats, vitamins, minerals, and water. It ensures proper growth, energy supply, and maintenance of body functions. Poor dietary habits can lead to malnutrition, obesity, and chronic diseases such as diabetes, hypertension, and heart diseases.

Components of a Balanced Diet
A balanced diet includes the following key components:

1. **Carbohydrates:** Main source of energy (rice, wheat, maize, potatoes)
2. **Proteins:** Essential for growth and tissue repair (pulses, milk, eggs, meat)
3. **Fats:** Provide energy and help in absorption of fat-soluble vitamins (oil, ghee, nuts)
4. **Vitamins:** Required for metabolic functions and immunity (fruits and vegetables)
5. **Minerals:** Important for body structure and physiological functions (milk, leafy vegetables)
6. **Water:** Essential for digestion, absorption, and temperature regulation

Health Benefits of a Balanced Diet
1. Reduces the risk of chronic diseases such as diabetes and cardiovascular disorders
2. Improves digestive health
3. Supports brain function and mental well-being
4. Strengthens bones and muscles
5. Promotes healthy skin and hair.

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BALANCED DIET
Vegetables & Fruits
Proteins
Balanced Diet
Grains & Cereals
Dairy & Water
Provides Key Nutrients
Carbohydrates
Proteins
Fats
Vitamins
Minerals
Energy
Growth
Immunity
Balanced Diet
Healthy Lifestyle
Exercise
Hydration
Adequate Sleep
Stress Management
Energy
Growth & Repair
Immunity
Healthy Lifestyle
Exercise
Hydration
Adequate Sleep
Stress Management
Maintains Healthy Weight
Enhances Energy & Immunity
Good Health
Enhances Energy & Immunity
Supports Growth & Development
Supports Growth & Development

Balanced Diet and Lifestyle

A balanced diet should be combined with a healthy lifestyle, including regular physical activity, adequate sleep, and stress management. Avoidance of junk food, processed foods, and excessive sugar intake is equally important.

Conclusion

A balanced diet is the cornerstone of good health and longevity. It ensures that the body receives all essential nutrients in the right amounts. Promoting awareness about healthy eating habits is crucial in preventing lifestyle-related diseases and improving overall well-being.

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Quinoa: A Novel Path Towards Healthy Eating

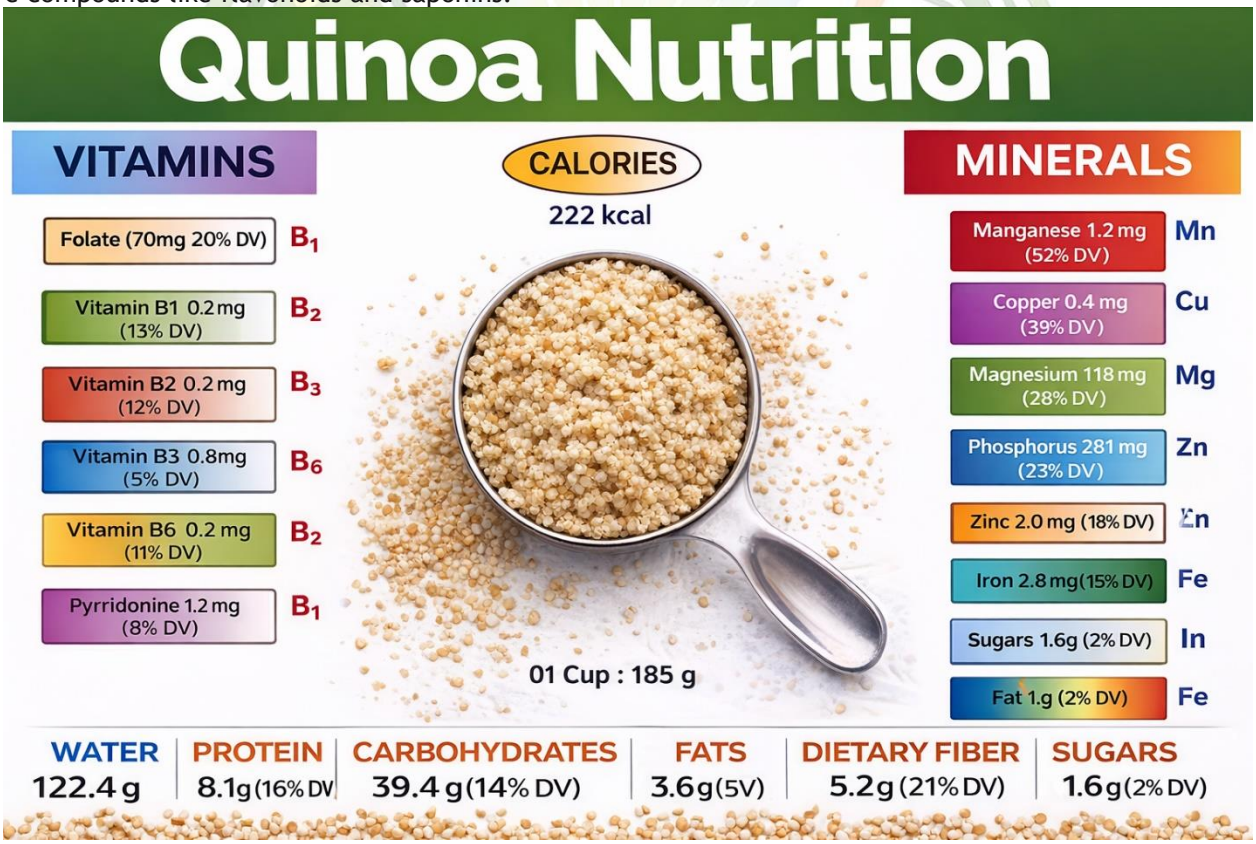
Article ID: 73528

Dr. Poorva Dashora[1]
[1]Assistant Professor (Home Science), Government College, Bassi, Chittorgarh, Rajasthan (312022).

Abstract
In the present era of nutritional insecurity and increasing lifestyle-related disorders, quinoa (Chenopodium quinoa Willd.) has emerged as a highly promising functional food. It is a gluten-free pseudocereal known for its superior nutritional composition, rich bioactive compounds, and adaptability to adverse environmental conditions. Due to its high-quality protein, essential amino acids, vitamins, and minerals, quinoa is gaining global recognition as a healthy dietary option and a potential crop for combating malnutrition and ensuring food security.

Introduction
Quinoa is an ancient crop originating from the Andean region of South America and belongs to the family Amaranthaceae. Although not a true cereal, it is consumed like grains and is therefore classified as a pseudocereal. Unlike cereals, pseudocereals are dicotyledonous plants cultivated for their edible seeds. Quinoa is particularly valued for its exceptional nutritional quality and ability to grow under harsh conditions such as drought, salinity, and poor soil fertility.

Nutritional Composition of Quinoa
Quinoa is rich in high-quality protein (12–16%) with all essential amino acids. It contains dietary fibre, healthy lipids, vitamins (C, E, B-complex), and minerals such as calcium, iron, magnesium, zinc, and potassium. It also contains bioactive compounds like flavonoids and saponins.



Health Benefits of Quinoa
Quinoa is gluten-free and suitable for celiac patients. It helps reduce cholesterol, regulate blood sugar, provides antioxidant effects, supports weight management, and has anti-inflammatory properties.

Agronomic Importance
Quinoa is tolerant to drought, salinity, and temperature stress. It grows well on marginal soils and requires low inputs, making it suitable for sustainable agriculture.

Processing and Utilization

Processing methods include soaking, germination, fermentation, cooking, and popping. It is used in porridges, soups, salads, bakery products, and beverages.

Conclusion

Quinoa is a highly nutritious and climate-resilient crop that contributes to food and nutritional security and helps prevent lifestyle diseases.

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Baobab or Mandu Imli or Adansonia – The Super Fruit from Malwa Region of India

Article ID: 73529

Dr. Arghya Mani[1]

[1]Assistant Director of Horticulture, Department of Food Processing Industries and Horticulture, Government of West Bengal, West Bengal.

Abstract

Baobab (*Adansonia digitata* L.), commonly referred to as "Mandu Imli" or "Khorasani Imli" in India, is an ecologically resilient and nutritionally superior tree species belonging to the family Malvaceae. Native to Africa and subsequently introduced into the Indian subcontinent through historical trade and cultural exchanges, the species has established localized populations in semi-arid regions such as Mandu and Dhar in Madhya Pradesh. The tree is distinguished by its extraordinary longevity, massive pachycaulous trunk capable of storing large volumes of water, and highly nutritious fruit pulp rich in vitamin C, dietary fibre, and bioactive compounds. Beyond its ecological importance, baobab has gained global recognition as a functional food and nutraceutical resource. The present review provides an in-depth synthesis of the taxonomy, origin, morphological adaptations, physiological mechanisms of drought tolerance, ecological significance, nutritional composition, ethnobotanical uses, and economic prospects of baobab, with particular emphasis on its underexploited potential in India. The review also highlights research gaps and future directions for sustainable utilization and conservation.

Introduction

The baobab (*Adansonia digitata* L.) is one of the most iconic and scientifically intriguing tree species in tropical ecosystems, often celebrated as the "Tree of Life" due to its extraordinary ability to support both ecological functions and human livelihoods. The species is indigenous to sub-Saharan Africa, where it forms an integral component of savanna ecosystems, but its presence in India represents a remarkable example of historical plant introduction and adaptation. Historical accounts suggest that baobab was introduced into the Indian subcontinent during the medieval period, possibly via Arab traders or during the reign of regional rulers such as Mahmud Khilji, facilitating its establishment in parts of central India (Wickens and Lowe, 2008).

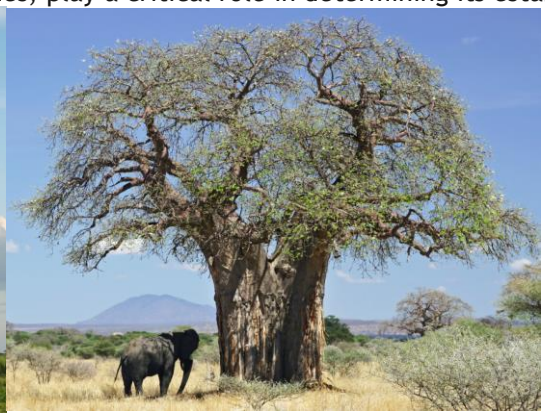
In India, baobab is locally known as "Mandu Imli" owing to its acidic pulp, which resembles tamarind in taste but differs significantly in botanical origin and composition. The species remains rare and geographically restricted, predominantly occurring in the Mandu and Dhar regions, where it has adapted to dry climatic conditions. Despite its limited distribution, baobab represents an important underutilized resource with immense potential for addressing nutritional security, climate resilience, and sustainable agricultural development.

Taxonomy, Origin and Biogeographical Distribution

The genus *Adansonia* comprises eight recognized species, including six endemic to Madagascar, one native to mainland Africa and the Arabian Peninsula, and one found in Australia. Among these, *Adansonia digitata* is the most widely distributed and economically significant species (Baum, 1995). The genus is taxonomically placed within the family Malvaceae, reflecting its evolutionary relationships with other economically important plant species.

Biogeographically, baobabs are believed to have originated in Gondwanan landmasses, with subsequent diversification occurring following continental drift. The presence of baobab in India has been attributed to anthropogenic introduction as well as possible long-distance dispersal mechanisms, including oceanic currents and trade-mediated seed movement (Wickens and Lowe, 2008). The restricted distribution of baobab in India suggests that ecological constraints, such as soil type, rainfall patterns, and temperature regimes, play a critical role in determining its establishment and survival.





Morphological and Anatomical Features

Baobab exhibits a unique morphological architecture characterized by a massive, swollen trunk, sparse canopy, and irregular branching patterns that give the tree its characteristic "upside-down" appearance. This peculiar morphology has fascinated botanists and ecologists alike, as it reflects specialized adaptations to arid environments. The trunk is composed of fibrous wood with high water-holding capacity, allowing the tree to act as a natural reservoir during periods of water scarcity (Sidibe and Williams, 2002).

Anatomically, the trunk consists of parenchymatous tissues interspersed with vascular elements, enabling efficient water storage and transport. The bark is smooth and relatively thin, yet resilient, providing protection against environmental stress. The leaves are palmately compound in mature trees, with leaflets that vary in shape and size depending on environmental conditions. The deciduous nature of the tree is a critical adaptation that reduces transpiration during dry seasons.

The reproductive biology of baobab is equally remarkable. The flowers are large, pendulous, and nocturnal, opening rapidly at dusk and remaining viable for a short duration. This ephemeral flowering strategy is closely associated with pollination by nocturnal animals, particularly bats, which are attracted by the strong fragrance and abundant nectar (Baum, 1995). The fruit is a woody, indehiscent capsule containing dry, powdery pulp and numerous seeds embedded within a fibrous matrix.



(a) Baobab fruit pulp



(b) Baobab red fiber/funicles



(c) Baobab seeds



(d) Baobab fruit pods



(e) Baobab fruit pod cracked open



(f) Baobab leaves

Physiological Adaptations and Drought Tolerance Mechanisms

The survival of baobab in arid and semi-arid environments is largely attributed to its exceptional physiological adaptations. The ability to store large quantities of water within its trunk allows the tree to maintain metabolic functions during prolonged dry periods. This water storage capacity can exceed 100,000 liters in mature individuals, providing a buffer against environmental stress (Patrut et al., 2018).

Baobab also exhibits phenological plasticity, with leaf emergence synchronized with rainfall and leaf shedding occurring during drought conditions. This strategy minimizes water loss and optimizes resource use efficiency. Additionally, the tree's root system is adapted to access deep soil moisture, further enhancing its drought tolerance. Recent studies have highlighted the vulnerability of baobab to climate change, particularly increased temperatures and altered precipitation patterns. The decline of some of the oldest baobab trees has been linked to dehydration and structural instability, underscoring the need for conservation efforts (Patrut et al., 2018).



Nutritional Composition and Functional Properties

The fruit pulp of baobab is widely recognized as a nutrient-dense food with significant health benefits. It is exceptionally rich in vitamin C, with concentrations that can exceed those of commonly consumed fruits such as oranges. In addition to vitamin C, the pulp contains high levels of dietary fiber, which contributes to digestive health and glycemic regulation (Chadare et al., 2009).

The mineral composition of baobab includes calcium, potassium, magnesium, and iron, making it a valuable dietary supplement in regions with micronutrient deficiencies. The presence of bioactive compounds, including polyphenols and antioxidants, further enhances its functional properties, providing protection against oxidative stress and chronic diseases. The pulp is commonly processed into beverages, powders, and food products, offering versatility in culinary applications. Its natural acidity and unique flavour profile make it suitable for incorporation into a variety of formulations, including juices, smoothies, and fermented products.

Processing and Value Addition Of Baobab

Processing and value addition of baobab (*Adansonia digitata* L.), locally known as Mandu Imli, have gained increasing attention due to the fruit's exceptional nutritional profile and functional properties. The fruit is characterized by a hard, woody shell enclosing a dry, powdery pulp interspersed with seeds and fibrous strands. Post-harvest processing typically begins with manual or mechanical cracking of the shell, followed by separation of pulp, seeds, and fibres. Unlike many fruits, baobab pulp is naturally dehydrated, which minimizes the need for energy-intensive drying processes and enhances its shelf stability (Chadare et al., 2009). The pulp is sieved and milled into a fine powder, which serves as a primary raw material for various value-added products.

Baobab pulp powder is widely utilized in the formulation of health beverages, instant drink mixes, smoothies, and fermented products owing to its high vitamin C content, natural acidity, and pleasant tangy flavour. It is also incorporated into bakery products such as biscuits, bread, and cakes to enhance nutritional quality and functional attributes. In addition, the pulp is used in the production of jams, jellies, syrups, and confectionery items, where it acts as a natural acidulant and flavouring agent (Sidibe and Williams, 2002). The seeds, often considered a by-product, are processed to extract edible oil rich in essential fatty acids, which has applications in both food and cosmetic industries. Roasted seeds can also be ground into flour and used as a protein supplement.

Furthermore, baobab pulp has gained recognition in the nutraceutical sector due to its antioxidant properties and high dietary fibre content, leading to the development of capsules, dietary supplements, and functional food ingredients. The integration of baobab into value chains offers significant opportunities for rural entrepreneurship, particularly in regions where the tree is naturally available. However, standardization of processing techniques, quality control, and market development remain critical for maximizing its commercial potential.

Ethnobotanical Importance and Traditional Knowledge Systems

Baobab has been an integral component of traditional knowledge systems in Africa, where it is utilized extensively for food, medicine, and material purposes. The fruit pulp is consumed directly or processed into beverages, while the leaves

are used as a nutrient-rich vegetable. The seeds are a source of oil, and the bark is used for making ropes and textiles (Sidibe and Williams, 2002). In India, the ethnobotanical utilization of baobab is comparatively limited, although local communities recognize its value as a food and medicinal resource. The fruit is occasionally used in traditional dishes and as a remedy for heat-related ailments. The cultural significance of baobab is also reflected in folklore, where it is often associated with resilience and longevity.

Economic Potential and Industrial Relevance

The global market for baobab products has expanded significantly in recent years, driven by increasing consumer demand for natural and functional foods. Baobab pulp powder is widely used in the food industry as a natural ingredient with high nutritional value. Its application in nutraceuticals and dietary supplements has further enhanced its economic importance. The seed oil of baobab is gaining popularity in the cosmetic industry due to its moisturizing and antioxidant properties. Additionally, the tree has potential applications in agroforestry systems, where it can contribute to soil conservation, carbon sequestration, and sustainable land management.

In India, the commercialization of baobab remains underdeveloped, presenting opportunities for research, value addition, and market development. The integration of baobab into horticultural and agroforestry systems could enhance income generation and promote sustainable agriculture.

Constraints, Research Gaps and Future Perspectives

Despite its numerous advantages, baobab faces several challenges that limit its widespread adoption and utilization. These include lack of awareness among farmers and consumers, limited availability of planting material, and insufficient research on cultivation practices. The absence of organized value chains further constrains its commercialization. Future research should focus on genetic characterization, propagation techniques, and agronomic practices to improve productivity and quality. The development of processing technologies and value-added products will be essential for enhancing its market potential. Conservation strategies are also critical to protect existing populations and ensure the sustainability of this unique species.

Conclusion

Baobab (*Adansonia digitata* L.) represents a unique convergence of ecological resilience, nutritional richness, and cultural significance. Its presence in India, though limited, offers valuable opportunities for diversification of agricultural systems and enhancement of nutritional security. The species holds immense promise as a climate-resilient crop and a functional food resource. However, realizing its full potential will require concerted efforts in research, conservation, and commercialization. The promotion of baobab as a sustainable and economically viable resource can contribute significantly to the development of resilient agricultural systems in the face of global environmental challenges.

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Combining Ability and Heterosis in Crop Plants: Advances and Applications

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A. Anisha[1]
[1]Ph.D. Scholar, Department of Genetics and Plant Breeding, College of Agriculture, PJTSAU.

Abstract
Combining ability and heterosis are fundamental concepts in plant breeding that play a crucial role in the development of high-yielding and resilient crop varieties. Combining ability, encompassing general combining ability (GCA) and specific combining ability (SCA), helps in identifying superior parental lines and understanding the genetic control of important traits, while heterosis refers to the enhanced performance of hybrids over their parents. Recent advances in Genomics have significantly improved the precision and efficiency of these approaches by enabling the identification of genetic factors underlying complex traits through tools such as Genome-Wide Association Studies and genomic selection. Additionally, emerging technologies like CRISPR-Cas9 offer new opportunities to enhance hybrid performance by targeted manipulation of genes. The integration of conventional breeding methods with modern genomic tools has accelerated the development of superior hybrids with improved yield, adaptability, and stress tolerance. This article highlights the advances and applications of combining ability and heterosis in crop plants, emphasizing their importance in achieving sustainable crop improvement and global food security.

Introduction
The continuous improvement of crop productivity is essential to meet the growing global demand for food, feed, and nutrition. Among the various genetic approaches employed in plant breeding, the concepts of combining ability and heterosis have played a pivotal role in the development of high-yielding crop varieties. Combining ability refers to the potential of parental lines to transmit desirable traits to their offspring, while heterosis, or hybrid vigor, describes the superior performance of hybrids over their parents. Together, these concepts form the backbone of hybrid breeding programs in crops such as maize, rice, and sorghum. With the advent of modern tools in **Genomics**, the understanding and application of combining ability and heterosis have evolved significantly, leading to more efficient and precise crop improvement strategies.

Advances and Applications in Combining Ability and Heterosis
Traditionally, combining ability has been assessed through mating designs such as line × tester and diallel analysis, which help breeders identify superior parents and cross combinations. It is broadly classified into general combining ability (GCA), which reflects additive gene effects, and specific combining ability (SCA), which is associated with non-additive gene actions such as dominance and epistasis. These analyses have been instrumental in selecting parents for hybrid development and understanding the genetic control of important agronomic traits.

Heterosis has been widely exploited in crop improvement due to its ability to enhance yield, vigor, and stress tolerance. The genetic basis of heterosis is complex and involves interactions among multiple genes. Advances in molecular biology and genomics have provided deeper insights into the mechanisms underlying heterosis. Techniques such as **Genome-Wide Association Studies** and quantitative trait locus (QTL) mapping have enabled the identification of genomic regions associated with hybrid performance. These approaches allow breeders to dissect complex traits and select superior hybrids with greater accuracy.

In recent years, the integration of genomic tools with conventional breeding methods has revolutionized the study of combining ability. Genomic selection, for instance, uses genome-wide marker data to predict the breeding value of parental lines and the performance of their hybrids. This reduces the need for extensive field evaluations and accelerates the breeding cycle. Additionally, gene-editing technologies such as **CRISPR-Cas9** offer new opportunities to manipulate specific genes associated with combining ability and heterosis, thereby enhancing hybrid performance.

The practical applications of combining ability and heterosis are evident in the development of high-yielding and climate-resilient hybrids. In crops like sorghum, the use of cytoplasmic male sterility (CMS) systems, combined with effective fertility restoration, has facilitated large-scale hybrid seed production. Moreover, the exploitation of genetic diversity from landraces and wild relatives has contributed to the development of hybrids with improved adaptability and nutritional quality. These advancements are particularly important in the context of climate change, where the need for resilient crop varieties is more urgent than ever.

Conclusion
Combining ability and heterosis remain central to the success of modern plant breeding programs. While traditional methods have laid a strong foundation, recent advances in genomics and biotechnology have significantly enhanced their application and effectiveness. The integration of molecular tools, predictive breeding approaches, and innovative

technologies is transforming the way breeders identify superior parental combinations and develop high-performing hybrids. Despite challenges such as the complexity of genetic interactions and environmental influences, ongoing research continues to unravel the underlying mechanisms and improve breeding efficiency. As agriculture faces increasing pressures from population growth and climate variability, the strategic use of combining ability and heterosis will play a crucial role in ensuring sustainable crop production and global food security.

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Arbuscular Mycorrhizal Fungi: Nature's Secret Weapon for Sustainable Agriculture

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Payal J. Kodavala[1], K. S. Jotangiya[2], Vaishali Dangar[3]
[1]Ph.D. Scholar, Deartment of Plant Pathology, JAU, Junaagadh.
[2]M.Sc., Deartment of Plant Pathology, NAU, Navsari.
[3]M.Sc., Deartment of Genetic & Plant Breeding, NAU, Navsari.

Abstract

Arbuscular mycorrhizal fungi (AMF) are a group of beneficial soil microorganisms that establish symbiotic associations with the roots of most terrestrial plants. These fungi play a crucial role in improving plant nutrient uptake, enhancing stress tolerance, and maintaining soil health. In the context of sustainable agriculture, AMF offer an eco-friendly alternative to chemical fertilizers and pesticides by promoting natural plant growth and resilience. This article explores the diversity, functional roles, and applications of AMF in agriculture, along with their contribution to plant disease management and environmental sustainability. The integration of AMF into farming practices can significantly reduce dependency on external inputs while improving crop productivity and soil fertility.

Introduction

Sustainable agriculture aims to meet the food demands of the present without compromising the ability of future generations to meet their needs. In recent decades, excessive use of chemical fertilizers and pesticides has led to soil degradation, environmental pollution, and reduced biodiversity. Therefore, there is a growing interest in biological approaches that enhance productivity while preserving ecological balance.

Arbuscular mycorrhizal fungi, belonging to the phylum Glomeromycota, form mutualistic relationships with plant roots by colonizing cortical cells and forming specialized structures known as arbuscules and vesicles. Through this association, plants supply carbohydrates to the fungi, while the fungi assist in the uptake of essential nutrients such as phosphorus, nitrogen, and micronutrients. This symbiotic relationship is considered one of the most widespread and ancient plant-microbe interactions, playing a pivotal role in terrestrial ecosystem functioning.

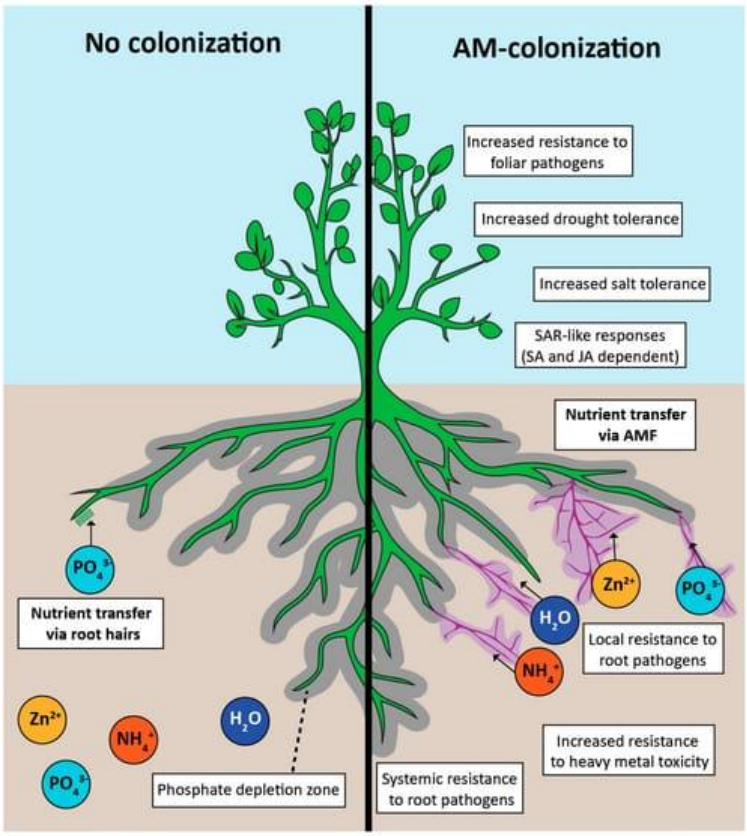


Figure:1. Comparative Illustration of Plant Growth with and Without AMF Colonization Showing Nutrient Uptake and Stress Resistance

Overview of Arbuscular Mycorrhizal Fungi

Arbuscular mycorrhizal fungi are obligate symbionts that depend on host plants for their survival and reproduction. They develop extensive hyphal networks in the soil, which significantly increase the surface area for nutrient absorption beyond the root zone. The formation of arbuscules within root cells facilitates efficient nutrient exchange between the plant and the fungus, making this association highly beneficial.

AMF are widely distributed across different ecosystems, including agricultural fields, forests, and grasslands. Their presence is influenced by soil type, climate, and cropping systems. In agricultural soils, AMF diversity is often reduced due to intensive farming practices such as deep tillage and excessive use of agrochemicals. However, conservation and augmentation of AMF populations can restore soil health and improve crop productivity.



Figure:2. Extensive Hyphal Network of Arbuscular Mycorrhizal Fungi Enhancing Root Surface Area

Factors Affecting Diversity of AMF

The diversity and distribution of AMF are influenced by several biotic and abiotic factors. Soil properties such as pH, texture, organic matter content, and nutrient availability play a critical role in determining AMF diversity. For instance, soils with moderate fertility and organic matter content tend to support a higher diversity of AMF species, while highly fertilized soils often show reduced diversity due to decreased plant dependence on fungal associations.

Agricultural practices also significantly impact AMF diversity. Conventional practices such as monocropping, heavy tillage, and excessive application of chemical fertilizers and fungicides can negatively affect AMF populations. In contrast, sustainable practices such as crop rotation, reduced tillage, organic amendments, and cover cropping promote AMF diversity and activity. Additionally, climatic factors such as temperature and moisture influence the survival and distribution of AMF in different regions.

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Roles of AMF in Agriculture

AMF play a vital role in enhancing plant growth and productivity. One of their primary functions is improving nutrient uptake, particularly phosphorus, which is often a limiting nutrient in soils. The fungal hyphae extend far beyond the root zone, accessing nutrients that are otherwise unavailable to plants. This leads to improved plant growth, yield, and overall health.

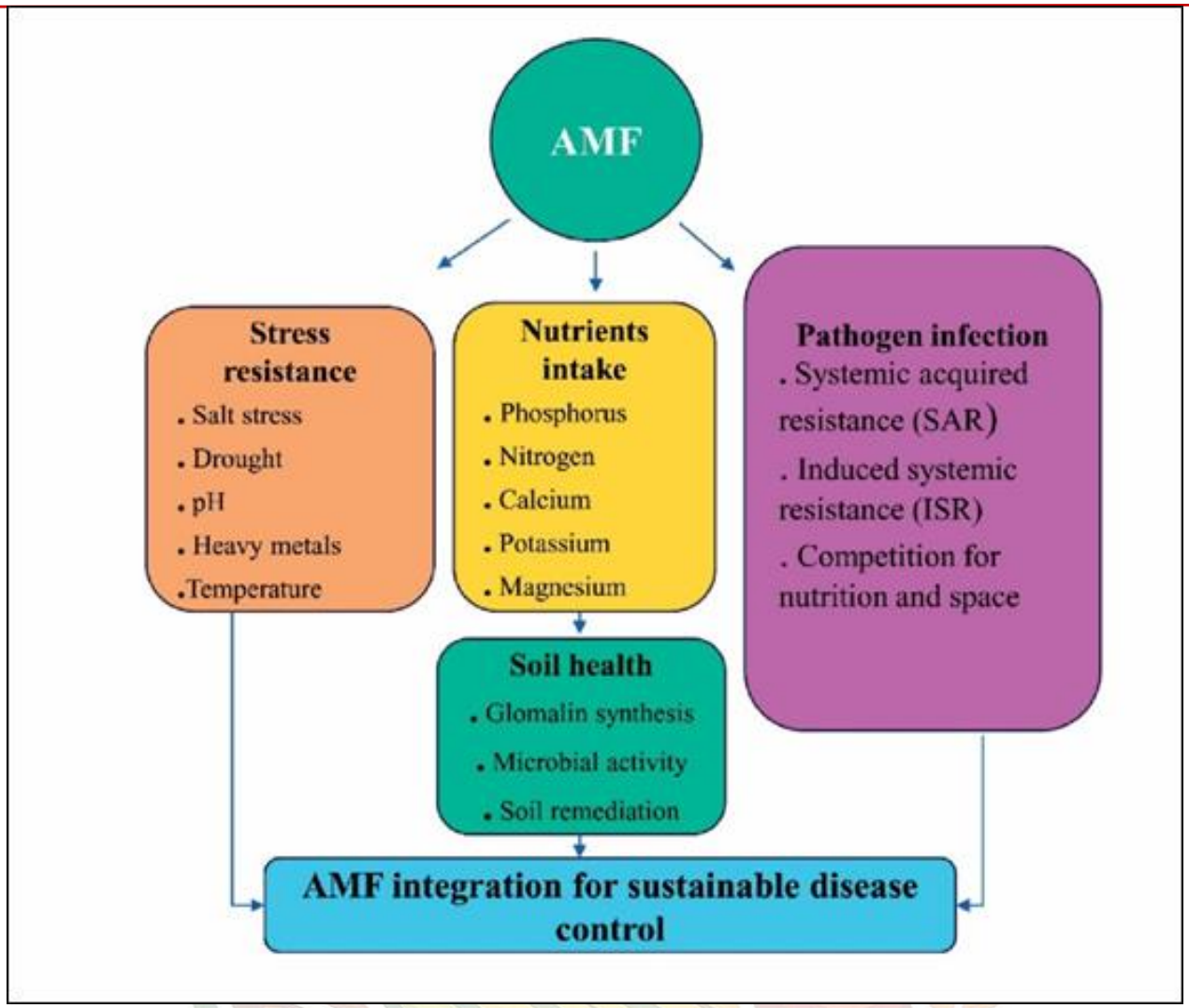


Figure: 3. Multifunctional Role of Arbuscular Mycorrhizal Fungi (AMF) in Nutrient Uptake, Stress Tolerance, Soil Health, and Disease Management

In addition to nutrient acquisition, AMF enhance plant tolerance to abiotic stresses such as drought, salinity, and heavy metal toxicity. They improve water uptake efficiency and help maintain osmotic balance in plants under stress conditions. Moreover, AMF contribute to soil structure by producing glomalin, a glycoprotein that binds soil particles together, thereby improving soil aggregation and stability. This results in better aeration, water retention, and reduced soil erosion.

AMF-Mediated Plant Disease Management

Arbuscular mycorrhizal fungi play a significant role in suppressing plant diseases caused by soil-borne pathogens. They enhance plant defense mechanisms by inducing systemic resistance, which prepares the plant to respond more effectively to pathogen attacks. This phenomenon, often referred to as mycorrhiza-induced resistance (MIR), strengthens the plant's immune system.

AMF also compete with pathogenic microorganisms for space and nutrients in the rhizosphere, thereby reducing pathogen establishment and proliferation. Furthermore, they improve plant nutrition and vigor, making plants less susceptible to infections. Studies have shown that AMF can reduce the severity of diseases caused by fungi, bacteria, and nematodes, making them an effective biological control agent in integrated disease management strategies.

Enhancing Agricultural Sustainability with AMF

The integration of AMF into agricultural systems offers a sustainable approach to crop production. By reducing the need for chemical fertilizers, AMF help lower production costs and minimize environmental pollution. Their ability to improve nutrient use efficiency ensures that crops receive adequate nutrition with reduced external inputs.

AMF also contribute to long-term soil fertility and ecosystem stability. Their role in improving soil structure, enhancing microbial diversity, and promoting carbon sequestration makes them essential for sustainable land management.

Incorporating practices such as biofertilizer application, organic farming, and conservation agriculture can enhance AMF populations and maximize their benefits in agricultural systems.

Conclusion and Future Prospects

Arbuscular mycorrhizal fungi are indispensable components of sustainable agriculture due to their multifaceted roles in plant growth, soil health, and disease management. Their ability to enhance nutrient uptake, improve stress tolerance, and suppress plant diseases makes them a valuable tool for eco-friendly farming practices. As the global demand for food continues to rise, the adoption of AMF-based technologies can contribute to achieving higher productivity with minimal environmental impact.

Future research should focus on the identification of efficient AMF strains, development of cost-effective inoculants, and understanding the interactions between AMF and other soil microorganisms. Advances in molecular biology and biotechnology can further enhance the application of AMF in agriculture. Promoting farmer awareness and integrating AMF into mainstream agricultural practices will be key to achieving sustainable and resilient farming systems.

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Status and Management of *Nilaparvata lugens* (Stal) (Hemiptera: Delphacidae) in Rice Ecosystems

Article ID: 73532

Gurjot Kaur[1]

[1]Department of Entomology, Punjab Agricultural University, Ludhiana, Punjab, India.

Introduction

Rice (*Oryza sativa* L.) is one of the most important and oldest crops of the world. More than one half of world's people consume rice as staple food (FAO, 2023). Worldwide there are several constraints in rice production, amongst them significant annual losses are caused by different insect pests and diseases (Kumar, 2019). Many insect pests and weeds have threatened production system of rice which causes significant yield losses (Fahad et al., 2020). Most important yield limiting factor among all the factors are pests. Due to intensification of agriculture following green revolution many rice insect pests such as planthoppers *viz.*, *Nilaparvata lugens* (Stal) and *Sogatella furcifera* (Horvath) and leaf folder, *Cnaphalocrocis medinalis* (Guenee) have emerged as major pests (Rajna and Subash, 2012).

Brown Planthopper Incidence in India

The brown planthopper (BPH), *N. lugens* (Stal) (Hemiptera: Delphacidae) is one of the most damaging rice insect pests in Asia that was originated as a result of green revolution and is of economic importance (Bottrell and Schoenly, 2018). BPH is a sap sucking pest as it sucks the cell sap from phloem tissues of rice plants and causes severe damage to plants due to dessication and ovipositor damage. It leads to condition called hopper burn and also acts as a vector for various viral diseases such as grassy stunt and ragged stunt (Cabauatan et al., 2009). The severity of BPH in India has increased in recent decades. There are several factors such as excessive application of nitrogenous fertilizers, dense planting and continuous rice cultivation (Horgan, 2018). Changes in these agricultural factors create favorable conditions for rapid multiplication of this pest. High humidity and warm temperatures further enhance its population growth. In addition, indiscriminate use of broad-spectrum insecticides disrupts natural enemy populations, leading to pest resurgence and resistance development. As a result, it causes significant economic losses in rice production (Lu et al., 2016).

Integrated Pest Management (IPM) of Brown Planthopper: Integrated pest management (IPM) is the most effective and sustainable strategy for controlling *N. lugens* in rice ecosystems. It involves the integration of multiple compatible approaches, including cultural, biological, mechanical, and chemical methods, to keep pest populations below economic threshold levels. IPM ensures effective pest control while maintaining ecological balance and reducing environmental risks (Heong et al., 2015). There are the following methods of IPM for *N. lugens*:

Cultural Control: Various cultural practices such as maintenance of optimum plant spacing, avoiding excessive use of nitrogen fertilizers, synchronized planting, water management and removal of weeds and alternate hosts should be performed to limit the further spread of BPH (Sogawa et al., 2015).

Host Plant Resistance (HPR): Through breeding and gene pyramiding many resistant rice varieties and improved cultivars have been developed. These varieties possess specific resistance genes (e.g., *Bph* genes) that reduce feeding, survival, and reproduction of the BPH (Jena et al., 2017).

Biological Control: For thousands of years, arthropod natural enemies have existed in this environment and have played roles to keep the pest species at levels below damage boundaries. Conservation of natural enemies such as spiders, mirid bugs (*Cyrtorhinus lividipennis*) and parasitoids plays a vital role in suppressing BPH populations and maintaining ecological balance in rice ecosystems (Heong et al., 2015).

Mechanical and Physical Control: Mechanical and physical methods play a supportive role in managing brown planthopper populations, especially under low to moderate infestation levels. Use of light traps for monitoring and mass trapping of adults, along with removal and destruction of heavily infested plants, helps in reducing BPH population and preventing its spread (Guo et al., 2017).

Chemical Control: Chemical control should be applied judiciously and only when brown planthopper populations exceed the economic threshold level. Selective insecticides such as pymetrozine, imidacloprid, triflumezopyrim, dinotefuran, and buprofezin are effective in managing the pest (IRRI, 2021). Application of chemicals should be directed towards the base of the plant where the insects congregate for better efficacy.

Conclusion

In conclusion, brown planthopper remains a major constraint to rice production in India due to its high reproductive capacity, adaptability, and ability to develop resistance. Sustainable management requires a holistic approach

integrating cultural, biological, host resistance, and chemical methods. Adoption of IPM practices and modern technologies will play a key role in minimizing losses and ensuring stable rice production in the future.

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Applications of Biotechnology

Article ID: 73533

Burri Ramesh[1]
[1]Assistant Professor, Genetics and Plant Breeding, SKYCAS College (ANGRAU), Etcherla.

Summary

Biotechnology is a multidisciplinary scientific domain that exploits living organisms, biological systems, or their derivatives to develop products and processes that are beneficial to human society. It encompasses a broad spectrum of disciplines, including molecular biology, genetics, biochemistry, and engineering, and has experienced rapid advancement over recent decades. The impact of biotechnology is extensive, influencing key sectors such as healthcare, agriculture, industry, and environmental management. In the medical field, it has contributed significantly to the development of novel therapeutics, vaccines, and diagnostic techniques. In agriculture, it has enhanced crop productivity, improved nutritional quality, and strengthened global food security. Furthermore, biotechnology has enabled the development of sustainable, eco-efficient materials and processes that support environmental conservation. Biotechnology is widely regarded as a transformative and forward-looking technology with substantial potential to improve human health, elevate standards of living, and promote environmental sustainability. The present paper aims to provide a comprehensive and systematic overview of biotechnology, including its definitions, classifications, and principal applications. It examines the foundational principles underlying the field and explores its diverse sub-disciplines. Additionally, the paper offers a critical analysis of the major applications of biotechnology across healthcare, agriculture, industry, and environmental sectors. Ultimately, it seeks to enhance scholarly understanding of biotechnology and its societal implications, while identifying prospective avenues for future research and innovation.

Introduction

Biotechnology is a multidisciplinary field that utilizes living organisms, cells, and biomolecules to develop products and processes that significantly impact human life and the environment. Rooted in disciplines such as molecular biology, genetics, and engineering, it applies biological agents like enzymes and microorganisms in areas ranging from pharmaceuticals and food production to advanced technologies such as gene therapy, nanotechnology, and recombinant DNA. In agriculture, biotechnology enhances crop yield, nutritional quality, and stress resistance, thereby supporting food security and climate resilience. Industrial applications include the production of biofuels, bioplastics, and eco-friendly materials, while environmental biotechnology contributes to pollution control, waste management, and sustainable energy generation. As a rapidly evolving "technology of hope," biotechnology plays a vital role in improving human health, promoting sustainability, and driving innovation in the knowledge-based economy, with vast potential for future research and development.

Applications in Medicine

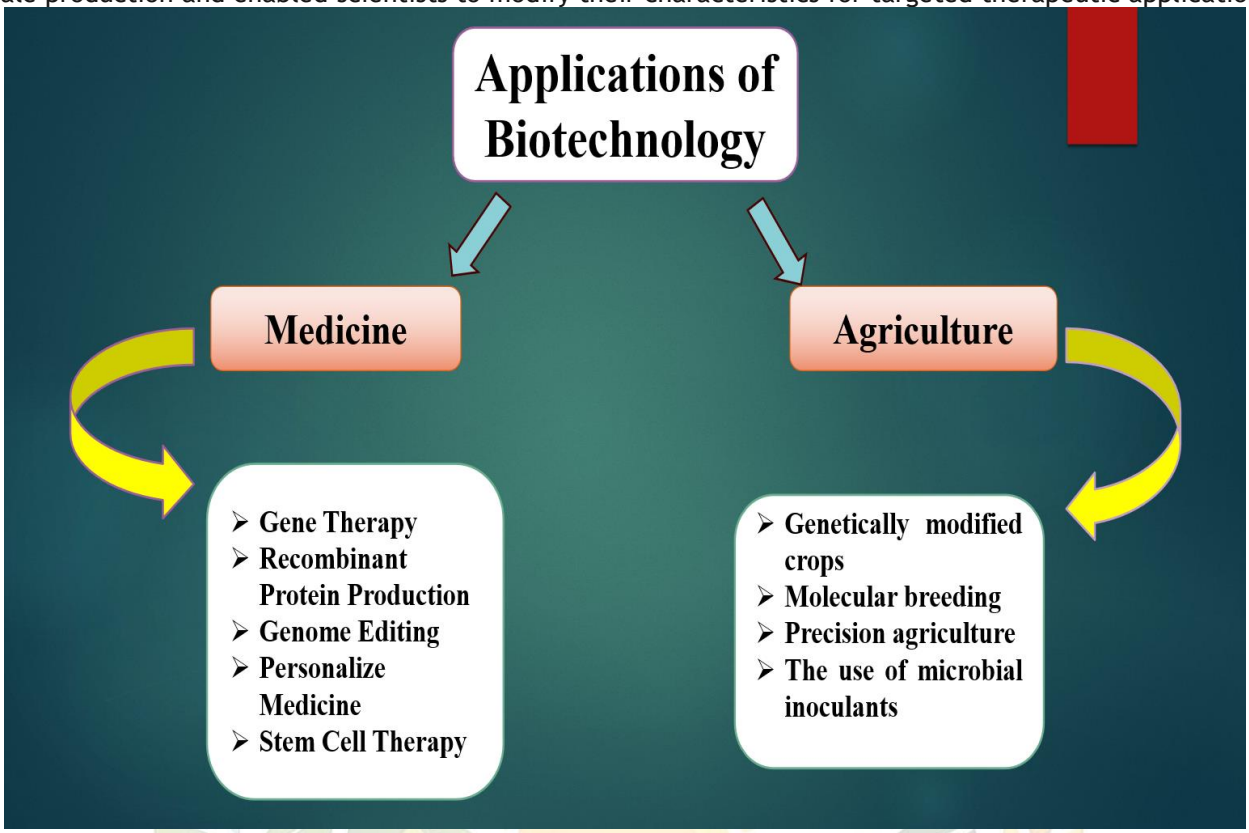
Gene Therapy: Gene therapy is a medical approach that involves introducing genetic material into cells to treat or prevent diseases. This is accomplished through various delivery techniques, including the use of viral vectors as well as non-viral methods such as electroporation. Gene therapy has been applied in targeting several disorders, including cystic fibrosis, muscular dystrophy, and certain forms of cancer, demonstrating its potential as a promising therapeutic strategy.

Recombinant Protein Production: Biotechnology has facilitated the large-scale synthesis of recombinant proteins that are widely used in therapeutic applications. These proteins are produced by genetically engineering host systems such as bacteria, yeast, or mammalian cells to express specific target proteins. Notable examples of recombinant protein therapeutics include insulin for the management of diabetes, growth hormone for treating growth deficiencies, and clotting factors used in the treatment of hemophilia.

Genome Editing: The ability to manipulate the genetic code has revolutionized medicine. Genome editing methods, including CRISPR-Cas9, enable precise alteration of genetic sequences in cells and whole organisms. These approaches hold substantial promise for therapeutic applications, particularly in the treatment of inherited genetic disorders, cancer, and infectious diseases.

Personalized Medicine: Recent developments in biotechnology have enabled the emergence of personalized medicine, an approach that customizes treatments based on an individual's specific genetic profile. This is made possible through methods such as genetic testing and pharmacogenomics, which examine how a person's genetic makeup influences their response to different medications.

Stem Cell Therapy: Stem cells possess the remarkable ability to differentiate into any cell type in the body, making them highly valuable for the treatment of various diseases and injuries. Advances in biotechnology have facilitated their large-scale production and enabled scientists to modify their characteristics for targeted therapeutic applications.



Applications in Agriculture

Genetically modified crops: Genetically modified crops are plants that have been scientifically altered to incorporate desirable characteristics, such as resistance to pests, diseases, or herbicides. This technology has been extensively adopted by farmers around the world and has demonstrated considerable economic and environmental advantages. Research indicates that GM crops can enhance yields by up to 25%, lower pesticide usage by approximately 37%, and reduce greenhouse gas emissions by nearly 22%.

Molecular breeding: Molecular breeding is a technique that utilizes molecular markers to identify and select desirable traits in plants, such as resistance to diseases or tolerance to drought. This approach has allowed plant breeders to develop improved crop varieties more efficiently, with enhanced accuracy and in a shorter time frame.

Precision agriculture: Precision agriculture refers to the use of advanced technologies such as GPS, sensors, and drones to observe crop growth and manage farming operations more effectively. This approach enhances the efficient use of resources like water and fertilizers, while also contributing to increased crop yields and better soil health.

The use of microbial inoculants: Microbial inoculants consist of beneficial living microorganisms applied to soil or seeds to support plant growth and overall health. These microbes enhance nutrient absorption, boost resistance against diseases and pests, and contribute to improved soil fertility.

Conclusion

Biotechnology represents a dynamic and transformative field that integrates multiple scientific disciplines to address critical challenges in healthcare, agriculture, industry, and environmental sustainability. Its wide-ranging applications have significantly improved human well-being and resource efficiency. As advancements continue, biotechnology holds immense promise for driving innovation, enhancing quality of life, and supporting sustainable development in the future.

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Sustainable Agricultural Waste Management: A Pathway to Improved Soil Quality and Resilient Farming Systems

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Ch. Robinsonsingh[1], Dr. Sandip Gargil[2]

[1]M. Tech (SWCE), Department of Irrigation and drainage Engineering Divison, ICAR-CIAE, Bhopal, India.
[2]Principal scientist and HOD-AEP, Department of Agricultural Energy and Power Division, ICAR-CIAE, Bhopal, India.

Abstract

Sustainable agriculture increasingly recognizes agricultural waste not as a disposal problem but as a valuable resource for restoring soil health and enhancing productivity. Crop residues, animal manures, agro-industrial by-products, and organic farm wastes, when managed scientifically, contribute significantly to soil fertility, structure, and biological activity. This article explores the types of agricultural waste, sustainable recycling methods, and their role in improving soil quality, nutrient availability, and long-term farm sustainability.

Keywords: Agricultural waste, Soil health, Organic matter, Sustainable farming, Circular agriculture.

Introduction

Modern agriculture faces the dual challenge of maintaining high productivity while preserving soil and environmental health. Continuous use of chemical fertilizers, residue burning, and poor waste disposal practices have led to declining soil organic matter, nutrient imbalance, and land degradation. Sustainable management of agricultural waste offers an eco-friendly solution by recycling nutrients back into the soil, reducing external inputs, and supporting climate-resilient farming systems.Agricultural waste includes crop residues, livestock manure, green biomass, food processing waste, and biodegradable farm by-products. Proper utilization of these materials transforms waste into wealth, aligning agriculture with circular economy principles.

Types of Agricultural Waste and their Potential

Crop Residues: Includes straw, stalks, husks, and leaves from cereals, pulses, and oilseeds. These residues are rich in carbon and help improve soil organic matter. It is mainly available in the agriculture field.

Animal Manure: Cow dung, poultry litter, and sheep or goat manure supply essential nutrients such as nitrogen, phosphorus, potassium, and micronutrients.

Agro-industrial: WasteSugarcane bagasse, press mud, rice husk, oilseed cakes, and fruit-processing waste contain organic carbon and minerals useful for soil amendment.

Green Waste: Weeds, cover crops, and green manure crops like sunhemp and dhaincha enhance nitrogen content and microbial activity.

Sustainable Waste Management Practices

1. Composting: Composting converts organic waste into stable humus-rich manure. Well-decomposed compost, Improves soil structure and water-holding capacity Enhances nutrient availability Supports beneficial soil microorganisms.

There two types composting. They are (a)Aerobic composting and Anaerobic composting:

a. Aerobic composting: Composting / break down of organic materials by microorganism using oxygen, the generating heat should be around 55 to 70^{0}C.The materials moisture should be 50%.

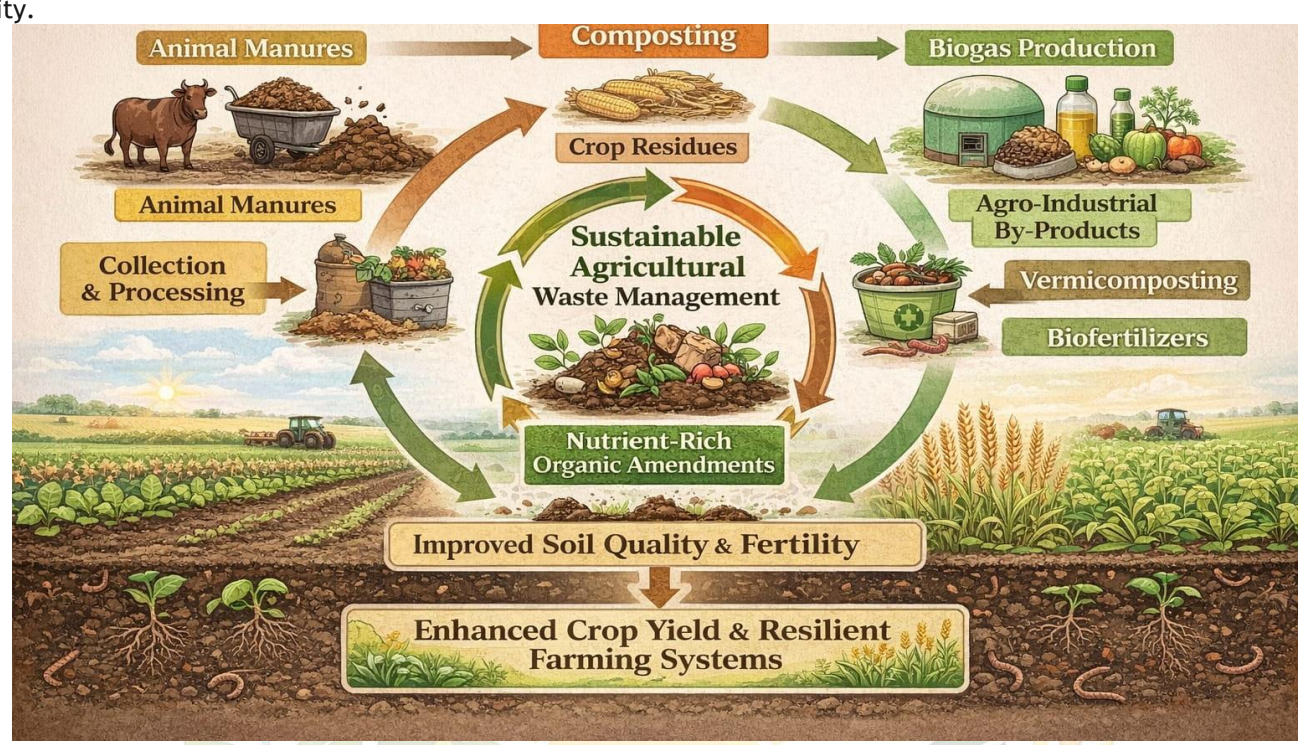
b. Anaerobic composting: Composting/breakdown of organic materials by microorganism without oxygen. It creates nutrient –rich, pathogen reduce compost.

2. Vermicomposting: Earthworms transform organic waste into nutrient-dense vermin compost containing plant growth promoters, enzymes, and beneficial microbes. It's a eco-friendly method for soil fertility and its is one of the oldest traditions for soil fertility. Earthworm required moist environment, area should be shaded and the temperature between 15 to 25^{0}C.

3. Mulching and Residue Retention: Leaving crop residues on the soil surface: Reduces soil erosion. Conserves moisture. Regulates soil temperature Enhances carbon sequestration. All the unwanted biodegradable part of the plant can cover the surrounding of the main plant. It can give surface cover and reduce the evaporation rate of the land suface.it keep moisture inside the soils.

4. Bio-char Application: Biochar produced from agricultural waste improves soil porosity, nutrient retention, and long-term carbon storage. All the organic waste heated up to 1000^{0}C without using oxygen. It improves soil structure and boosting plant health.

5. Green Manuring and Cover Crops: Incorporation of green biomass improves nitrogen fixation, suppresses weeds, and boosts soil microbial diversity. green manure crops like sun hemp and dhaincha enhance nitrogen content and microbial activity.



Impact on Soil Quality

Sustainable recycling of agricultural waste positively influences key soil health parameters:

1. Physical properties: Its Improves the ability to retain soil moisture, reduced compaction, better aeration of the soil. Protect the soil surface and reducing soil erosion

2. Chemical properties: Enhanced nutrient availability such as Nitrogen (N), Phosphorous(P) And Potassium (K), and it maintains pH level of the soil, reduced nutrient leaching

3. Biological properties: Increased microbial biomass, enzyme activity, and earthworm population. Soils rich in organic matter show better resilience to drought, floods, and intensive cropping.

Environmental and Economic Benefits

Reduction in residue burning and greenhouse gas emissions. Lower dependence on chemical fertilizers. Improved long-term productivity and yield stability. Enhanced farm profitability through reduced input costs. Promotion of climate-smart and regenerative agriculture.

Challenges and Way Forward

Despite its benefits, adoption of sustainable waste management faces challenges such as lack of awareness, labour constraints, and limited access to technology. Addressing these issues requires:

1. Farmer training and extension support
2. Policy incentives for residue management
3. Integration of waste recycling into farming systems
4. Promotion of on-farm composting and bio-inputs.

Conclusion

Sustainable agricultural waste management is a cornerstone of soil health restoration and resilient food systems. By converting farm waste into valuable soil amendments, farmers can enhance soil quality, reduce environmental degradation, and ensure long-term agricultural sustainability. Embracing waste recycling is not only an ecological necessity but also an economic opportunity for future-ready agriculture. It give more productivity of the yield. And economy for the farmer. Free from chemical and fertilizers.

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Palmyrah fruit (*Borassus flabellifer* L.): The Most Underutilized Palm

Article ID: 73535

Trinayanee Sharma[1]

[1]Ph.D. scholar, Department of Plantation, Spices, Medicinal and Aromatic Crops, Bidhan Chandra Krishi Viswavidyalaya, Nadia, West Bengal.

Introduction

The Palmyrah tree, which grows in many semi-arid areas, is an essential part of sustainable living since it provides a wealth of nutrients. Palmyrah is a prime example of nature's abundance, from its nutrient-rich sap, Neera, to the various uses of its leaves, fibers, and timber in crafts and building. Its adaptability is further highlighted by its function in the manufacture of biofuel and its significance in landscaping and agriculture. In order to ensure that Palmyrah's heritage endures for future generations, it is crucial to carefully balance environmental preservation with human requirements.

Health Benefits and Nutritional Value

Palmyrah fruits are rich in vitamins, minerals, and antioxidants, aiding in digestion and skin conditions. Packed with vitamins B and C, iron, calcium, and potassium, they are a perfect addition to a balanced diet.

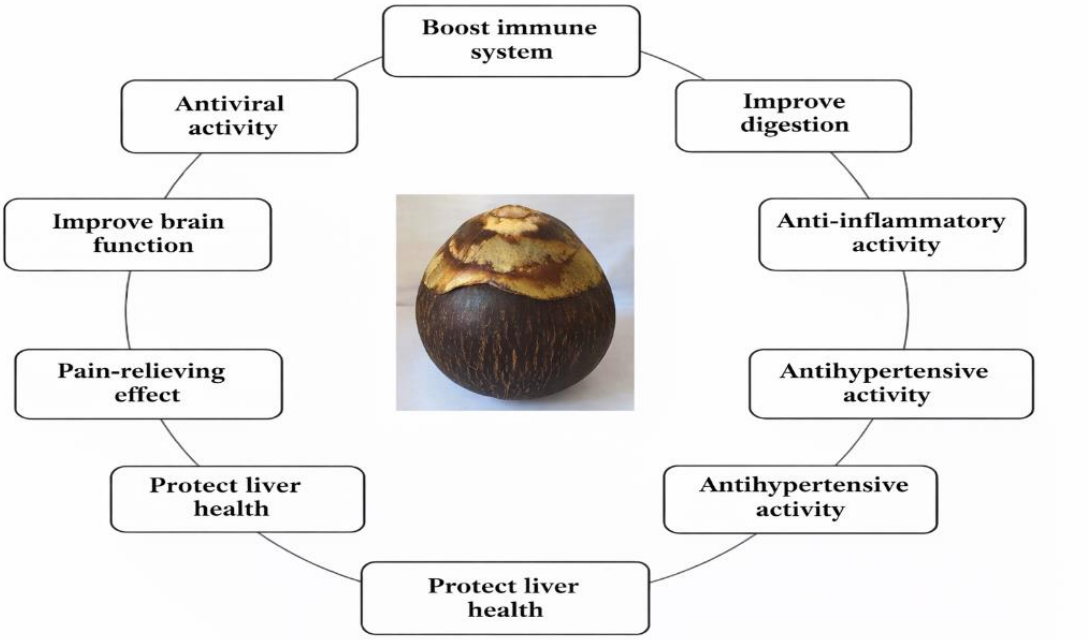


Figure 1. Health benefits of Palmyrah fruit pulp

Neera

Nutrient rich Neera is a sweet sap that contains important nutrients like ascorbic acid, riboflavin, and thiamine. It is made from the inflorescence of the palmyrah tree. Its phytochemicals, like as vitamin C, help manage hypertension by lowering blood pressure and lowering the risk of cancer. Neera acts as a powerful health remedy because of its high potassium content, which encourages good blood circulation. The beverage has many therapeutic benefits in addition to a high nutritional value and deliciousness. The drink has many therapeutic benefits in addition to its high nutritional content and deliciousness. Iron and vitamin deficiencies can be treated using it as a supplement. It enhances general health when taken consistently,. Neera has no negative effects when taken in quite high doses. As a supplement, it can also help individuals in leprosy, asthma, and anaemia. Additionally, it can be used to manufacture a variety of confections, including milk sweets, ice cream, jaggery, sweet syrup, palm sugar, toddy, sweet drinks, toffees, and palm candies.

Toddy

Fermented Delicacies Toddy, or fresh palm juice, naturally ferments to produce alcohol. A tiny amount of reducing sugars can be found in fresh juice. Alcohol is produced through the fermentation of glucose by naturally occurring yeasts in the sap. Acetobacter further facilitates this process by converting the alcohol to acetic acid, or vinegar. One day after

tapping is the ideal time to consume fresh juice because of its low vinegar level. Toddy's alcohol concentration is approximately 5%.

Vinegar

Vinegar is made by fermenting palm sap in direct sunshine for longer than two hours. The most significant component in the vinegar that is produced is acetic acid. This acetic acid is created when ethanol ferments. After fermentation, Acetobacter partially oxidize ethanol to acetic acid. The fermentation vessel is covered with a cloth to prevent contamination. When the alcoholic fermentation is over, the palm wine begins to turn into vinegar. Acetic acid bacteria are involved in the acetic fermentation of the palm wine. Four weeks are given for the wine to ferment. The procedure is permitted to occur at room temperature. To obtain the finished product, a thick film called the mother of vinegar is filtered out at the end of the procedure (Ghosh *et al.*, 2012).

Jaggery

An essential component of Indian cooking is jaggery, also known as gur. Jaggery is very delicious because of its sweetness and earthy undertones that make up its flavour profile. Although it is consumed all around the world, Gur is particularly well-liked and popular in India, where it is a necessary component of most sweet cuisines. Additionally, jaggery is a crucial component of Ayurveda, or traditional Indian medicine. Sugarcane and palm jaggery both provide immediate heat and energy but compared to cane sugar, jaggery is a far healthier option.

Economic Potential and Future Perspectives

Palmyrah pulp can be used to make a wide variety of food and drink items, such as juices, jams, jellies, sauces, and chocolate desserts, it has substantial potential for economic growth. Additionally, Palmyrah pulp extracts can be used to create nutraceuticals, dietary supplements, and functional food items that support wellbeing and health (Uluwaduge *et al.*, 2007). This adaptability makes Palmyrah pulp a useful ingredient in the health-conscious food industry and increases the variety of products that consumers can choose from.



Figure 2. Value added products of Palmyrah fruit

Conclusion

Palmyrah pulp has a wider economic influence than only product development. Particularly in rural areas where the Palmyrah palm is plentiful, its cultivation and processing provide revenue and job opportunities for farmers, processors, and entrepreneurs across the supply chain. Local communities' participation in the production process improves livelihoods and strengthens the region's economy. Growing consumer awareness makes it easier for companies to invest in palmyrah pulp, which boosts economic growth even more.

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Cashew Nutshell Liquid (CNSL): A Sustainable Industrial Resource

Article ID: 73536

Trinayanee Sharma[1]
[1]Ph.D. scholar, Department of Plantation, Spices, Medicinal and Aromatic Crops, Bidhan Chandra Krishi Viswavidyalaya, Nadia, West Bengal.

Introduction

A special agro-industrial byproduct made from cashew nut (*Anacardium occidentale*) shells is called cashew nut shell liquid (CNSL). It is a thick, dark brown liquid found in the cashew shell's honeycomb structure. CNSL was once thought of as waste, but because of its diverse industrial uses and rich chemical makeup, it has now become a significant renewable resource. The main phenolic chemicals that give CNSL its remarkable chemical reactivity and adaptability are anacardic acid, cardanol, and cardol. CNSL is becoming known as an environmentally friendly substitute in a number of industries due to growing concerns about environmental sustainability and reliance on petroleum-based products.

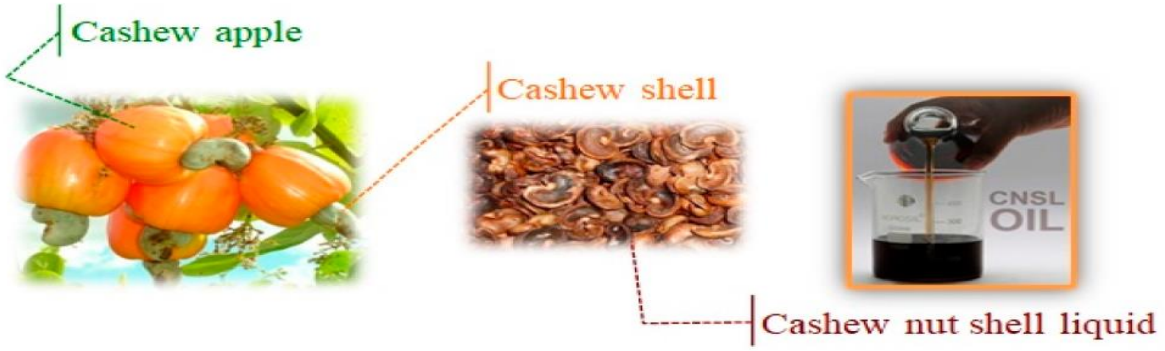


Figure 1. Cashew pedicel, fruit, and mesocarp filled with CNSL

Chemical Nature and Properties

CNSL is categorized into two types:
1. Natural CNSL – extracted using solvents and retains original composition
2. Technical CNSL – obtained through heating, rich in cardanol

Table 1. Composition of natural, technical, and distilled CNSL. Prepared based on data from:

Cardanol	Anacardic Acid	Cardol	2-Metylcardol	Polymeric Materials	
3–10%	60–70%	10–20%	2–3%	-	Natural CNSL
60–70%	<5%	10–20%	2–3%	7–10%	Technical CNSL
>90%	Not detected	<5%	Not detected	-	Distilled CNSL (180–200 °C)

(Bloise et al., 2023)

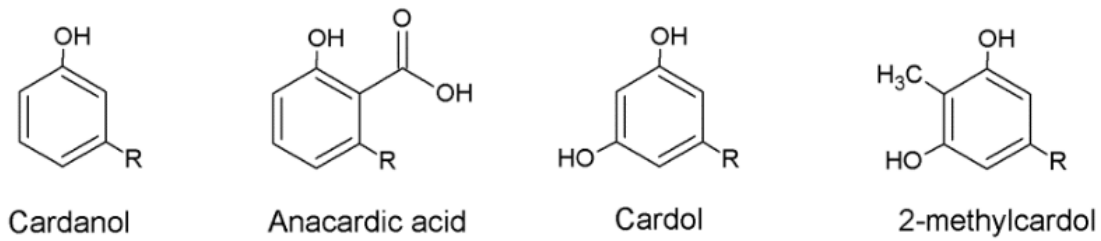


Figure 2. Components of CNSL

Its key properties include:
a. High thermal stability
b. Excellent antioxidant characteristics
c. Hydrophobic nature

d. Reactive phenolic structure

These properties make CNSL highly suitable for chemical modifications and industrial applications.

Benefits of Cashew Nutshell Liquid

Renewable and Eco-friendly Resource- CNSL is derived from agricultural waste, making it a renewable and biodegradable material. Its use reduces dependency on fossil fuels and supports sustainable development.

Cost-effective Raw Material- Since it is a byproduct of the cashew industry, CNSL is relatively inexpensive and widely available, especially in cashew-producing countries like India.

Environmental Advantages- It has very low toxicity compared to petrochemicals also reduced carbon footprint. Additionally, it supports circular economy by utilizing waste.

Excellent Chemical Versatility- CNSL can function as an antioxidant, plasticizer and polymer precursor due to its phenolic structure.

Corrosion Resistance and Protective Properties- CNSL-based compounds exhibit strong corrosion resistance and are used to protect metals in harsh environments.

Applications of CNSL

CNSL has diverse applications across multiple industries:

Polymer and Resin Industry:

a. Used in phenolic resins and epoxy resins.
b. Acts as a plasticizer and modifier.
c. Enhances flexibility and durability of polymers.
d. Also used as a compatibilizer in polymer blends, improving material stability.

Paints, Coatings, and Adhesives:

a. CNSL derivatives are used in anti-corrosive paints.
b. Provides water resistance and durability.
c. Used in varnishes and surface coatings.

Oil and Gas Industry: CNSL is gaining attention as a green oilfield chemical:

a. Corrosion inhibitors
b. Lubricants
c. Emulsifiers and demulsifiers
d. Enhanced oil recovery agents

These applications help replace harmful petrochemical-based additives.

Pharmaceutical and Agricultural Uses:

a. Used in insecticides and pesticides
b. Shows antimicrobial and medicinal properties
c. Potential use in drug formulations

Biofuel and Energy Sector: CNSL can be processed into as biofuel and fuel additives. This contributes to renewable energy development.

Advanced Materials and Nanotechnology: Recent research explores CNSL in Nanocomposites, UV-protective compounds and Sustainable advanced materials. This expands its use in high-tech industries.

Future Prospects of CNSL

Shift Towards Green Chemistry- With increasing environmental regulations, industries are moving toward bio-based alternatives. CNSL is expected to replace many petrochemical products due to its eco-friendly nature.

Expansion in Global Markets- Growing demand in coatings, automotive and energy sectors. Increasing processing capacity in cashew-producing countries.

Development of Advanced Derivatives

Future research focuses on:

1. Functionalized CNSL compounds
2. High-performance polymers
3. Nano-engineered materials

Role in Circular Economy

CNSL utilization promotes:

1. Waste valorization
2. Sustainable industrial development
3. Reduced environmental pollution.

Challenges to Overcome

Despite its potential, CNSL faces some limitations:

1. Variation in composition due to source
2. Need for advanced processing techniques
3. Scalability and standardization issues

Addressing these challenges will be crucial for large-scale industrial adoption.

Conclusion

With significant industrial significance, cashew nutshell liquid (CNSL) is a promising renewable resource. It is a competitive substitute for petroleum-based products because to its distinct chemical structure, affordability, and eco-friendliness. CNSL has many uses that support sustainable development, ranging from coatings and polymers to energy and medications.

CNSL is anticipated to have a big impact on green chemistry and circular economy systems in the future thanks to continuing research and technical developments. When this agricultural waste is used properly, it can be turned into a useful industrial resource that benefits the economy and the environment.

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Precision Nitrogen Management for Improving Soil Health and Nitrogen Use Efficiency in Sustainable Agriculture

Article ID: 73537

Iliya Hassan Abubakar[1], Dr. Kunal Narwal[1]
[1]School of Agriculture, Sanskaram University, Jhajjar, Haryana (124108)

Abstract
Nitrogen can be seen as one of the most important essential macro nutrient required in large quantity for crop production, but its improper use has become a major problem for agriculture today. Over application of nitrogen not only affects nitrogen use efficiency it also causes soil degradation and pollution. This study aims to highlight the importance of precision nitrogen management as a sustainable practice for improving soil health which includes soil organic matter, soil microorganisms, soil nutrient balance and soil structure as well as its impact on nitrogen use efficiency. Precision nitrogen management comprises of the optimal application of nitrogen at the right time and location through the use of tools like soil testing, crop sensors and decision support systems. This practice ensures that there is no loss of nitrogen through leaching, volatilization or runoff. The results obtained from the study suggest that precision management of nitrogen has demonstrate potential to improve efficiency in nitrogen uptake, reduce costs and boost soil biology. This has shown the potential to improve soil conditions that are advantageous to the sustainability of cropping systems. Moreover, reduction in nitrogen losses leads to reduce greenhouse gases and water pollutants, which are beneficial to environmental sustainability objectives. In conclusion, precision management of nitrogen has shown potential to be a practical approach to reach agronomic as well as environmental sustainability objectives. This approach not only addresses issues that are associated with the use of nitrogen but also shows potential to boost healthy soils as well as sustainable cropping systems. The study has demonstrate the potential to be adopted to attain maximum benefits across different agro-ecological regions.

Keywords: Nitrogen Use Efficiency (NUE), Precision Nitrogen Management, Soil Health, Sustainable Agriculture, Nutrient Management.

Introduction
Nitrogen (N) is one of the most important macro nutrient required by crops in larger quantity for their growth and productivity, contributing significantly to global food security. However, the inefficient utilization remains one of the major challenge in modern agriculture. Research show that only about **30% to 50% of nitrogen supplied is effectively utilized by crops**, while the remaining is lost through leaching, volatilization and runoff (Kumar et al., 2025). These losses not only decrease nitrogen use efficiency (NUE) but also contribute in polluting the environment such as greenhouse gas emissions and water pollution. Inefficient nitrogen management practices like blanket fertilizer recommendations do not consider the variations in soil fertility and crop nutrient requirements. This inefficiency has leads to the development of precision nitrogen management (PNM) practices that match nitrogen supply with crop demand. Precision nitrogen management involves the use of modern tools such as remote sensing, decision support systems and site specific nutrient management to improve fertilizer application. According to Rattan Lal (2016), improving soil health through better nutrient management is important for sustainable agricultural productivity.

Concept of Precision Nitrogen Management
Precision nitrogen management can be achieved by adopting the principle of applying the right nitrogen source, at the right rate, at the right time and in the right place (4R nutrient stewardship). This can be achieved through the use of modern approaches such as Leaf Color Chart (LCC), GreenSeeker sensors, SPAD meters, remote sensing and AI based decision tools. Sensor based nitrogen applications have been demonstrated to be efficient for achieving proper synchronization of nutrient demand and nutrient availability, which contributes to increase NUE based on ICAR-based research (D et al., 2025). Furthermore, new technologies such as mobile-based advisory tools (e.g nitrogen management apps) have shown strong potential in improving fertilizer efficiency under field conditions (Upadhyay et al., 2026).

Effects on Nitrogen Use Efficiency (NUE)
Precision nitrogen management have significant impact on Nitrogen Use Efficiency (NUE) by minimizing losses and increasing uptake efficiency. Study by V et al. (2024) shows that: Agronomic NUE increased up to 60.1% under optimized nitrogen management, Recovery efficiency increased up to 87% using LCC based application. Similarly, precision based nitrogen management in maize systems achieved yields of: 6.01 to 6.33 t/ha under optimized nitrogen scheduling, compared to lower yields under conventional practices (Upadhyay et al., 2026). These findings indicates that precision approaches improves not only nitrogen use efficiency but also crop productivity.

Case Studies: India (ICAR-Based Evidence) and Sub-Saharan Africa (Including Northern Nigeria)

Recent reports from the Indian Council of Agricultural Research show the effectiveness of precision nitrogen management in rice-wheat systems. The result indicate that nitrogen application based on guide of Leaf Color Chart (LCC) improved NUE significantly, Split nitrogen application maximizes yield and nutrient uptake and integration of nano-urea reduced fertilizer input without compromising yield (D et al., 2025). In conservation agriculture systems, irrigation management and precise nitrogen application improved both water and nitrogen use efficiency simultaneously, showing a great sustainability benefits (Gupta et al., 2023).

While site-specific high-resolution data in Northern Nigeria are still emerging, trends observed in Sub-Saharan Africa indicate a comparable trend. Key observations shows that low baseline soil fertility limits NUE, blanket fertilizer application leads to inefficient nutrient use and precision approaches such as split application and micro dosing significantly improve yields. Field based agronomic studies show that improved nitrogen timing and placement can increase yield and NUE in maize-based systems under semi-arid conditions. These findings are very relevant to Northern Nigeria, where similar agro-ecological conditions exist.

Comparative Assessment of India and Nigeria

Parameter	India	Northern Nigeria / SSA
Technology Level	High (sensors, apps)	Low to Moderate
Nitrogen Use Efficiency (NUE) (%)	50 to 60%	30 to 50%
Yield Response	High	Moderate to High
Limitation	Cost of technology	Access & awareness

While both regions benefit from precision nitrogen management, technology integration level determines efficiency gains.

Environmental Implications

Precision nitrogen management contributes significantly to environmental sustainability by reducing nitrous oxide (N_2O) emissions and minimizing nitrate (NO_3^-) leaching thereby preventing environmental pollution and enhancing ecological sustainability.

Conclusion

Precision nitrogen management describe a practical and effective way for improving nitrogen use efficiency and soil health in agricultural systems. By adjusting nitrogen application with crop demand, it reduces environmental losses while enhancing productivity and sustainability. The integration of precision tools, farmer education and policy support is crucial for implementing these practices across different agro-ecological regions. Ultimately, precision nitrogen management is essential for achieving long-term agricultural and environmental sustainability.

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Integrated Pest Management (IPM) Strategies for Sustainable Agriculture

Article ID: 73538

Dr. Nagendra Kumar[1]

[1]Associate Professor and P.I., AICRP on Honey Bees and Pollinators, Department of Entomology, PGCA, Dr. RPCAU, Pusa, Bihar.

Abstract

Integrated Pest Management (IPM) is an ecologically sound and economically viable approach to pest control that integrates diverse management strategies to maintain pest populations below economically damaging levels. It emphasizes prevention, monitoring, and the judicious use of control measures, thereby minimizing reliance on synthetic pesticides. IPM plays a crucial role in ensuring sustainable agricultural production by conserving biodiversity, improving environmental quality, and enhancing crop productivity. This review comprehensively discusses the principles, components, ecological basis, technological advancements, implementation challenges, and future prospects of IPM in the context of sustainable agriculture.

Introduction

Agricultural systems worldwide are under continuous threat from insect pests, plant pathogens, nematodes, and weeds, which collectively cause significant yield and quality losses. It is estimated that pests are responsible for up to 30–40% of global crop losses annually. Historically, pest management has relied heavily on chemical pesticides; however, indiscriminate use has resulted in severe consequences, including pesticide resistance, environmental pollution, disruption of ecological balance, and risks to human and animal health.

Integrated Pest Management (IPM) emerged as a response to these challenges, providing a holistic and sustainable alternative. IPM is a knowledge-intensive strategy that integrates biological, cultural, physical, and chemical tools to manage pest populations in an economically and environmentally sound manner (Pretty et al., 2015). Unlike conventional approaches, IPM focuses on long-term prevention and ecosystem stability rather than short-term eradication.

Concept and Evolution of IPM

The concept of IPM evolved from the idea of "integrated control" introduced in the 1950s, which emphasized combining biological and chemical methods in a compatible manner. Over time, the approach expanded to include ecological principles, pest population dynamics, and economic considerations.

The development of economic threshold levels (ETLs) marked a turning point in pest management by enabling rational decision-making. IPM further evolved with the incorporation of agroecology, biotechnology, and digital agriculture tools, transforming it into a multidisciplinary framework.

Modern IPM is now regarded as a cornerstone of sustainable agriculture, integrating ecological knowledge with advanced technologies to enhance pest management efficiency (Stenberg, 2017).

Principles of Integrated Pest Management

IPM is based on a set of core principles that guide its implementation in agricultural systems.

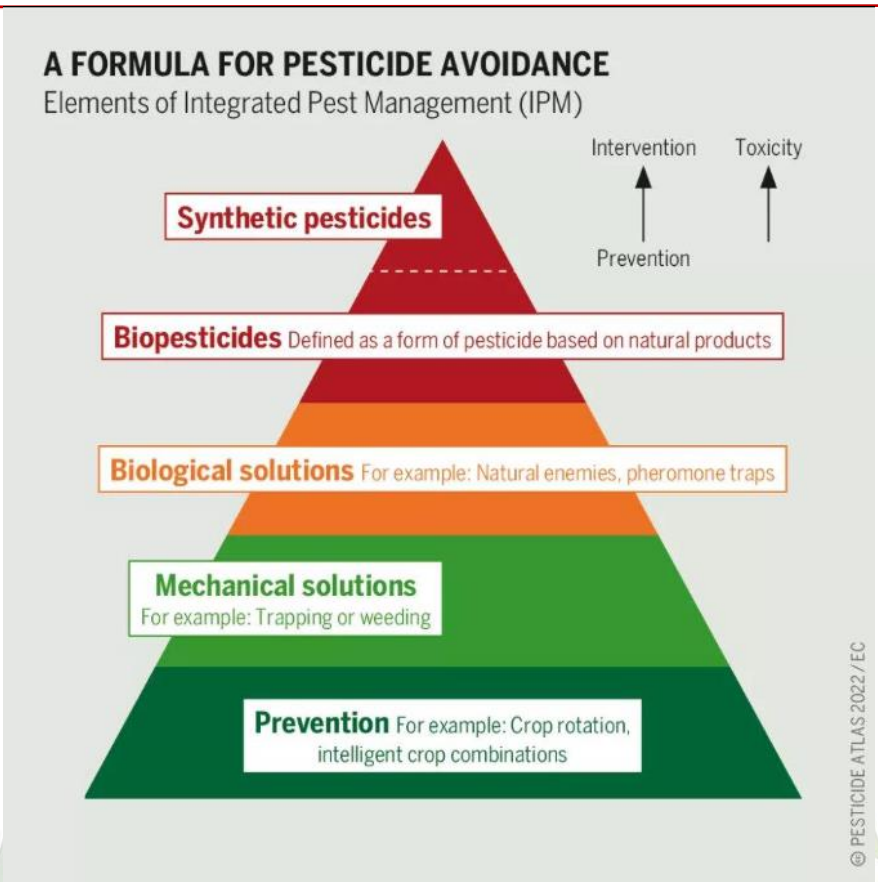
1. Prevention and Avoidance: Preventive strategies aim to reduce pest establishment and proliferation by creating unfavourable conditions for pests. These include crop rotation, use of certified seeds, resistant varieties, proper irrigation management, and field sanitation. Preventive measures form the first line of defence in IPM systems.

2. Monitoring and Surveillance: Regular monitoring of pest populations and natural enemies is essential for effective decision-making. Monitoring techniques include visual inspection, pheromone traps, light traps, sticky traps, and remote sensing technologies. Accurate pest identification is critical to avoid mismanagement.

3. Economic Threshold Level (ETL): The economic threshold level represents the pest population density at which control measures must be implemented to prevent economic loss. This principle ensures that interventions are economically justified and prevents unnecessary pesticide applications.

4. Integration of Control Methods: IPM emphasizes the integration of multiple compatible control strategies, ensuring synergistic effects and reducing dependence on any single method. This integration enhances sustainability and resilience.

5. Risk Minimization: The approach prioritizes environmentally safe and socially acceptable methods, minimizing risks to non-target organisms, including beneficial insects, humans, and wildlife.



Components of IPM Strategies

1. Cultural Control: Cultural practices play a fundamental role in IPM by altering the agroecosystem to make it less conducive to pest development. Crop rotation disrupts pest life cycles, while intercropping and mixed cropping reduce host plant availability. Adjusting planting dates can help avoid peak pest infestation periods. Field sanitation, including removal of crop residues and infected plant material, reduces inoculum sources.

Soil health management through organic amendments and biofertilizers enhances plant vigour and resistance to pests. Cultural control is cost-effective and environmentally benign, making it a cornerstone of IPM.

2. Biological Control: Biological control involves the use of natural enemies such as predators, parasitoids, and pathogens to regulate pest populations. Predators such as ladybird beetles and lacewings feed on aphids and other soft-bodied insects, while parasitoids like *Trichogramma* spp. parasitize insect eggs.

Microbial biocontrol agents, including bacteria, fungi, and viruses, are widely used as biopesticides. Conservation biological control, which focuses on protecting and enhancing existing natural enemies, is a key strategy in IPM. Biological control contributes to long-term pest suppression and ecological balance (Stenberg, 2017).

3. Mechanical and Physical Control: Mechanical and physical methods involve direct removal or exclusion of pests. These include handpicking, trapping, tillage, mulching, and the use of barriers such as nets and row covers. Solarization and temperature-based treatments are also effective against soil-borne pests. These methods are particularly useful in small-scale farming and organic agriculture.

4. Host Plant Resistance: The use of pest-resistant crop varieties is an effective and sustainable strategy in IPM. Resistance may be morphological, biochemical, or genetic in nature. Advances in plant breeding, marker-assisted selection, and genetic engineering have facilitated the development of resistant varieties. Host plant resistance reduces reliance on chemical pesticides and is compatible with other IPM components.

5. Chemical Control: Chemical pesticides are used as a last resort in IPM and are applied judiciously based on monitoring and ETL. Selective pesticides that target specific pests while sparing beneficial organisms are preferred. The adoption of safer formulations, reduced dosages, and precision application techniques minimizes environmental and health risks.

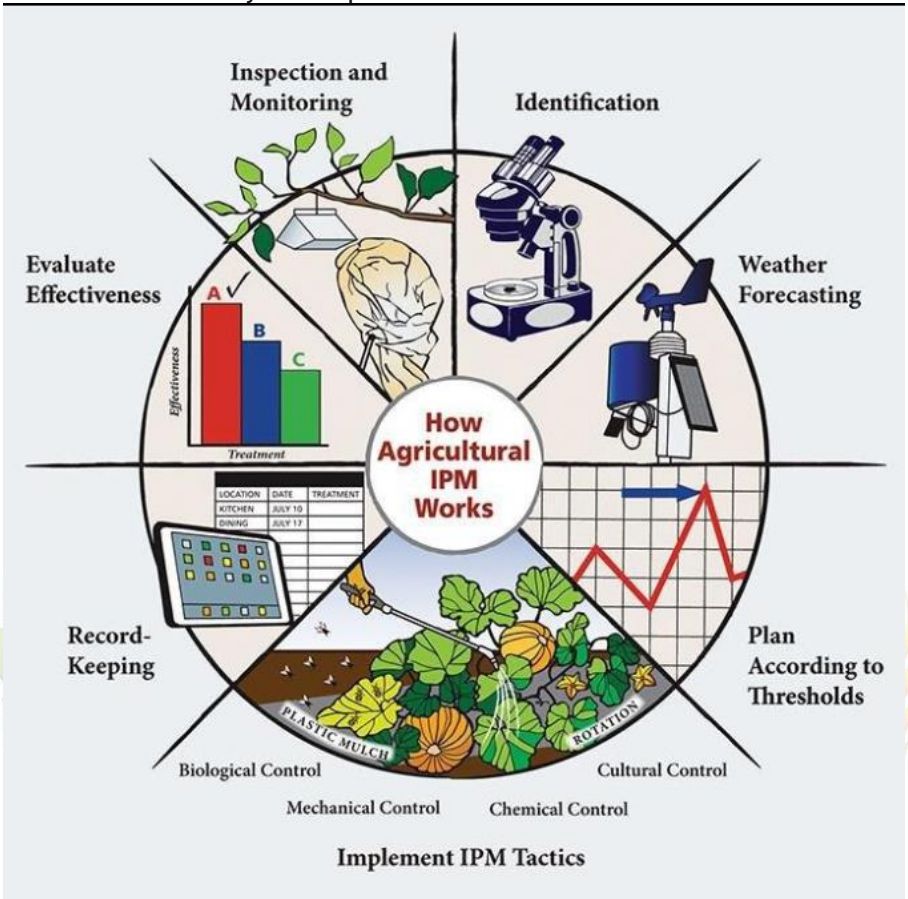
Ecological Basis of IPM

IPM is deeply rooted in ecological principles, particularly the understanding of pest population dynamics, food webs, and ecosystem interactions. Agroecosystems are complex and dynamic, with multiple trophic levels influencing pest populations. Enhancing biodiversity through habitat diversification promotes natural pest regulation. The concept of

ecological balance is central to IPM, where the goal is to maintain pest populations at manageable levels rather than complete eradication. Ecological engineering, such as the introduction of flowering plants to attract natural enemies, further strengthens pest suppression mechanisms.

Decision-Making and Economic Considerations

Effective IPM relies on informed decision-making based on scientific data and economic analysis. Decision support systems (DSS) and predictive models are increasingly used to forecast pest outbreaks and guide interventions. Economic thresholds ensure that pest control measures are cost-effective and prevent unnecessary inputs. Cost-benefit analysis is essential to evaluate the economic viability of IPM practices.



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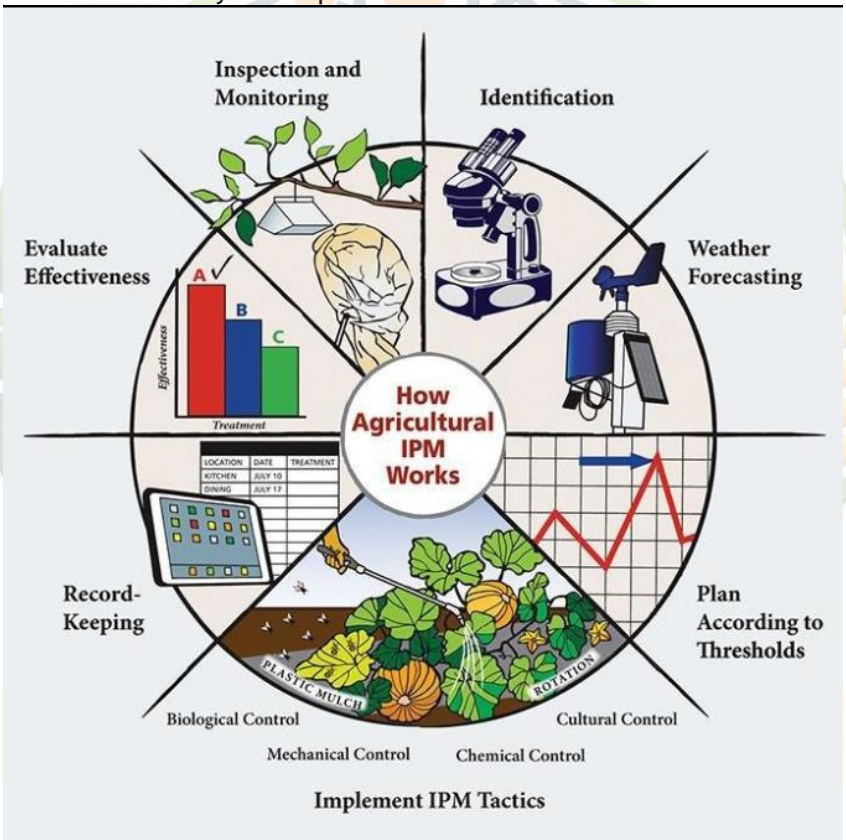
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Technological Advancements in IPM

Recent advancements in technology have revolutionized IPM implementation.

1. Precision Agriculture: Precision agriculture tools such as drones, remote sensing, and GPS-based systems enable real-time pest monitoring and site-specific management. These technologies improve accuracy and reduce input costs.

2. Biotechnology: Biotechnological innovations, including genetically modified crops and RNA interference (RNAi), provide new tools for pest control. These approaches offer targeted and environmentally friendly solutions.

3. Biopesticides: Biopesticides derived from natural sources are gaining popularity due to their safety and specificity. They include microbial pesticides, botanical extracts, and pheromones.

4. Digital Agriculture and AI: Artificial intelligence and machine learning are being integrated into IPM for pest identification, forecasting, and advisory services. Mobile-based applications provide real-time recommendations to farmers. These innovations enhance the efficiency, scalability, and adaptability of IPM systems (Zhou et al., 2024).

Role of IPM in Sustainable Agriculture

IPM is integral to sustainable agriculture as it balances productivity with environmental conservation. It reduces chemical pesticide use, thereby lowering environmental pollution and preserving biodiversity. IPM enhances ecosystem services such as pollination and natural pest control. It also contributes to soil health by reducing chemical inputs and promoting organic practices. By improving resource use efficiency and reducing production costs, IPM increases farm profitability and resilience. It aligns with the principles of sustainable intensification and climate-smart agriculture (Pretty et al., 2015).

Constraints and Challenges in IPM Adoption

Despite its benefits, IPM adoption faces several challenges. Lack of awareness and technical knowledge among farmers remains a major barrier. Limited availability of quality biocontrol agents and inputs also restricts implementation. Economic constraints, including initial costs and uncertain returns, discourage adoption. Institutional and policy support is often inadequate, and extension services may not effectively disseminate IPM knowledge. Behavioural resistance to change and reliance on chemical pesticides further hinder adoption.

Future Prospects of IPM

The future of IPM lies in integrating advanced technologies with ecological knowledge. Climate change is expected to alter pest dynamics, necessitating adaptive and resilient IPM strategies. The integration of genomics, artificial intelligence, and precision agriculture will enhance pest management efficiency. Landscape-level IPM and community-based approaches will play a crucial role in managing pests at a broader scale. Policy support, capacity building, and farmer participation will be essential for widespread adoption.

Conclusion

Integrated Pest Management represents a sustainable and scientifically robust approach to pest control in modern agriculture. By integrating multiple control strategies and emphasizing ecological balance, IPM reduces environmental impact while maintaining crop productivity.

Its successful implementation requires interdisciplinary collaboration, technological innovation, and strong policy support. As agriculture faces increasing challenges from climate change and resource constraints, IPM will remain a key strategy for achieving sustainable and resilient food systems.

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Insect Resistance to Pesticides Mechanisms and Management Strategies

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Dr. Nagendra Kumar[1]

[1]Associate Professor and P.I., AICRP on Honey Bees and Pollinators, Department of Entomology, PGCA, Dr. RPCAU, Pusa, Bihar.

Abstract

Insect resistance to pesticides has become a critical constraint in modern agriculture and vector control systems. The repeated and often indiscriminate use of insecticides has accelerated the evolution of resistant insect populations, compromising the effectiveness of pest control strategies. Resistance arises through a range of genetic, biochemical, physiological, and behavioral adaptations that enable insects to survive lethal doses of pesticides. This review provides an in-depth discussion of the mechanisms underlying insecticide resistance, including metabolic detoxification, target-site modification, reduced penetration, and behavioral avoidance. It also examines the genetic and ecological factors influencing resistance development, along with cross-resistance and multiple resistance phenomena. Furthermore, the review highlights modern diagnostic approaches for resistance detection and presents comprehensive management strategies, including chemical, biological, cultural, and biotechnological interventions. Emphasis is placed on integrated pest management (IPM) as a sustainable approach to delay resistance evolution and ensure long-term pest control efficacy.

Introduction

Insect pests continue to pose a major threat to global agricultural productivity, causing significant quantitative and qualitative losses in crop yield. Chemical insecticides have historically played a dominant role in pest management due to their rapid action and broad-spectrum activity. However, the intensive and prolonged use of these chemicals has led to the emergence of resistance in numerous insect species worldwide. Insecticide resistance is defined as a heritable reduction in sensitivity of an insect population to a pesticide that was previously effective at controlling it (Guedes et al., 2019).

The phenomenon of resistance is a clear demonstration of evolutionary adaptation under strong selection pressure. Over time, susceptible individuals are eliminated, while resistant individuals survive and reproduce, leading to the establishment of resistant populations. This issue has become increasingly serious in both agricultural pests and vectors of human diseases, necessitating a deeper understanding of resistance mechanisms and management strategies.

Evolutionary and Genetic Basis of Resistance

The development of insecticide resistance is fundamentally an evolutionary process driven by natural selection. Within any insect population, genetic variability exists, including rare alleles that confer resistance. When exposed to insecticides, individuals carrying these alleles survive and pass them on to subsequent generations. As a result, the frequency of resistance genes increases rapidly in the population.

Resistance may be governed by single genes (monogenic resistance) or multiple genes (polygenic resistance). Monogenic resistance often leads to rapid and high levels of resistance, whereas polygenic resistance develops gradually. The inheritance pattern of resistance can be dominant, recessive, or co-dominant, influencing the rate at which resistance spreads.

Factors such as short generation time, high fecundity, and multiple generations per year significantly accelerate resistance evolution. Additionally, gene flow between populations through migration can facilitate the spread of resistance traits across geographical regions (Tabashnik et al., 1990).

Mechanisms of Insecticide Resistance

Resistance mechanisms in insects are diverse and often occur simultaneously within a population, resulting in complex resistance phenotypes.

1. Metabolic Resistance: Metabolic resistance is the most widespread and significant mechanism of insecticide resistance. It involves the enhanced detoxification of insecticides by specific enzyme systems before they can reach their target sites. The primary enzyme groups involved include cytochrome P450 monooxygenases, carboxylesterases, and glutathione S-transferases. These enzymes metabolize insecticides into less toxic or more easily excretable forms. Overexpression or amplification of genes encoding these enzymes is commonly observed in resistant populations. In some cases, mutations in regulatory regions lead to increased enzyme production. Metabolic resistance can confer cross-resistance to multiple insecticides, particularly those with similar chemical structures or detoxification pathways (Shamjana et al., 2021).

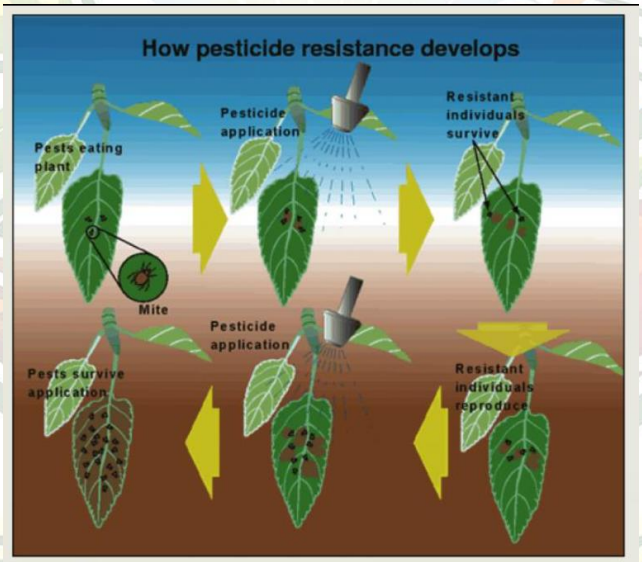
2. Target-Site Resistance: Target-site resistance arises from mutations in the proteins that serve as targets for insecticides. These mutations reduce the binding affinity of the insecticide, thereby diminishing its toxic effect. One of the most well-known examples is the knockdown resistance (kdr) mutation in voltage-gated sodium channels, which confers resistance to pyrethroids and DDT. Similarly, mutations in acetylcholinesterase result in resistance to organophosphates and carbamates, while alterations in GABA receptors confer resistance to cyclodienes. Such mutations often have significant implications for pest control, as they directly interfere with the mode of action of insecticides. In some cases, multiple mutations may accumulate, leading to higher levels of resistance (Dang et al., 2017).

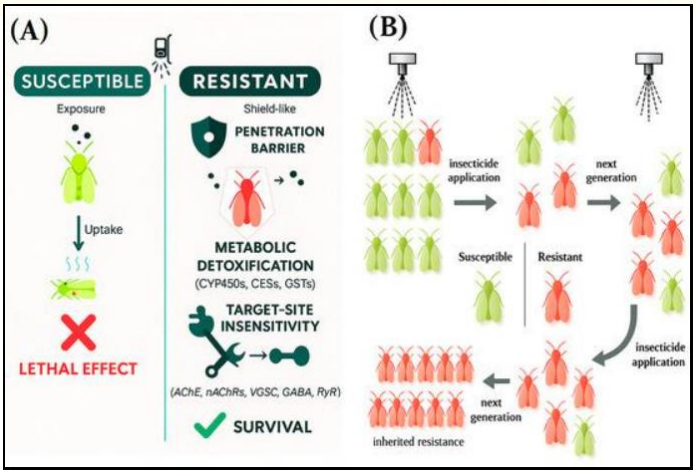
3. Reduced Penetration (Cuticular Resistance): Reduced penetration, also known as cuticular resistance, involves structural changes in the insect cuticle that limit the absorption of insecticides. Thickening of the cuticle or changes in its lipid composition can slow down the rate at which insecticides penetrate the insect body.

Although this mechanism alone may not confer high levels of resistance, it can act synergistically with other mechanisms such as metabolic resistance to enhance overall resistance levels. This combined effect can significantly reduce the efficacy of insecticides (Shamjana et al., 2021).

4. Behavioural Resistance: Behavioural resistance involves changes in insect behaviour that reduce exposure to insecticides. These changes may include avoidance of treated surfaces, reduced feeding on treated plants, altered oviposition behaviour, and increased mobility. Behavioural resistance is particularly important in field conditions, where insects can actively avoid insecticide exposure. Although it may not involve biochemical changes, it plays a crucial role in reducing the effectiveness of pest control measures (Boyer et al., 2012).

5. Cross-Resistance and Multiple Resistance: Cross-resistance occurs when resistance to one insecticide confers resistance to another, usually due to shared modes of action or detoxification pathways. For example, enhanced activity of detoxifying enzymes may confer resistance to multiple insecticides within the same chemical class. Multiple resistance refers to the presence of resistance to two or more insecticides with different modes of action within the same population. This situation is particularly challenging for pest management, as it limits the availability of effective control options (Guedes et al., 2019).





Factors Influencing Resistance Development

The development of resistance is influenced by a combination of biological, ecological, and operational factors. Frequent and indiscriminate use of insecticides imposes strong selection pressure, accelerating resistance evolution. Sublethal doses and improper application methods further exacerbate the problem. Biological factors such as high reproductive rate, short life cycle, and genetic variability enhance the adaptive potential of insect populations. Ecological factors, including climate, host plant availability, and natural enemy dynamics, also play a role. Agricultural practices such as monoculture cropping systems and lack of crop rotation create favourable conditions for pest population buildup and resistance development. Additionally, the absence of refugia, where susceptible insects can survive, contributes to rapid resistance evolution.

Detection and Monitoring of Resistance

Early detection and continuous monitoring of resistance are essential for effective management. Bioassays remain the most commonly used method, providing information on the susceptibility of insect populations to different insecticides. Biochemical assays are used to measure enzyme activity associated with metabolic resistance, while molecular techniques enable the identification of specific resistance genes and mutations. Techniques such as polymerase chain reaction (PCR), quantitative PCR, and next-generation sequencing have greatly enhanced the precision and efficiency of resistance detection. Recent advances in omics technologies, including genomics, transcriptomics, and proteomics, have provided deeper insights into resistance mechanisms and facilitated the development of diagnostic markers (Tabashnik et al., 1990).

Management Strategies for Insecticide Resistance

1. Chemical Control Strategies: Chemical control remains an important component of pest management, but it must be used judiciously. Rotation of insecticides with different modes of action is a key strategy to delay resistance development. The use of mixtures and synergists can enhance efficacy and reduce the likelihood of resistance. Proper dosing, timing, and application methods are critical to minimizing selection pressure. Avoiding unnecessary applications and adhering to recommended guidelines are essential for sustainable pesticide use.

2. Integrated Pest Management (IPM): Integrated Pest Management (IPM) is a holistic approach that combines multiple control methods to manage pest populations sustainably. It emphasizes the use of economic thresholds, monitoring, and environmentally friendly practices to reduce reliance on chemical pesticides. IPM plays a crucial role in resistance management by minimizing selection pressure and promoting the use of diverse control strategies.

3. Biological Control: Biological control involves the use of natural enemies such as predators, parasitoids, and pathogens to suppress pest populations. These agents provide long-term and environmentally sustainable pest control without contributing to resistance development. The integration of biological control into pest management programs reduces the need for chemical insecticides and helps maintain ecological balance.

4. Cultural and Mechanical Practices: Cultural practices such as crop rotation, intercropping, sanitation, and planting time adjustment disrupt pest life cycles and reduce population buildup. Mechanical methods, including traps and manual removal, provide additional control options. These practices are particularly important in reducing the initial pest population and lowering the reliance on chemical control.

5. Host Plant Resistance and Biotechnology: The development of resistant crop varieties through conventional breeding and genetic engineering is an effective strategy for pest management. Transgenic crops expressing insecticidal proteins, such as Bt toxins, have been widely adopted. However, resistance to Bt crops has been reported, highlighting the importance of refuge strategies and resistance monitoring. Advances in biotechnology, including RNA interference (RNAi) and gene editing, offer promising tools for future pest control.

6. Resistance Management Programs: Structured resistance management programs, such as those recommended by the Insecticide Resistance Action Committee (IRAC), provide guidelines for the sustainable use of insecticides. These programs emphasize mode-of-action classification, rotation, and integration with non-chemical control methods.

Future Perspectives

The future of resistance management lies in the integration of advanced technologies and ecological approaches. Genomic and transcriptomic studies are providing new insights into resistance mechanisms, enabling the development of targeted control strategies. Emerging technologies such as CRISPR-based gene editing and RNAi offer potential for highly specific pest control. Additionally, the role of insect microbiomes in detoxification and resistance is an area of growing interest. Sustainable pest management will require a multidisciplinary approach involving researchers, farmers, policymakers, and industry stakeholders.

Conclusion

Insect resistance to pesticides is a complex and dynamic problem that poses a significant threat to agricultural sustainability and public health. Understanding the underlying mechanisms and factors influencing resistance

development is essential for designing effective management strategies. The adoption of integrated pest management practices, combined with continuous monitoring and innovation, is critical for delaying resistance evolution and ensuring long-term pest control success.

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Biological Control Agents: Role Of Natural Enemies in Pest Management

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Dr. Nagendra Kumar[1]
[1]Associate Professor and P.I., AICRP on Honey Bees and Pollinators, Department of Entomology, PGCA, Dr. RPCAU, Pusa, Bihar.

Abstract
Biological control represents a vital pillar of sustainable agriculture, relying on the use of natural enemies to regulate pest populations in an ecologically balanced manner. Natural enemies such as predators, parasitoids, pathogens, and competitors are integral to maintaining ecosystem stability and reducing crop losses. Their role in pest suppression not only minimizes dependence on chemical pesticides but also supports biodiversity conservation and environmental health. This review provides an in-depth analysis of biological control agents, their classification, ecological roles, mechanisms of action, and integration into Integrated Pest Management (IPM) systems. The article further explores advances, constraints, and future directions in the field of biological control.

Introduction
The increasing demand for food production coupled with environmental concerns has necessitated the adoption of sustainable pest management strategies. Biological control, defined as the use of living organisms to suppress pest populations, has emerged as an effective alternative to chemical-based approaches. The concept is deeply rooted in ecological principles, particularly the natural regulation of populations through trophic interactions.

Natural enemies are indispensable components of agroecosystems and contribute significantly to pest suppression under both natural and managed conditions. These organisms maintain pest populations below economic threshold levels and prevent the occurrence of pest outbreaks. The ecological basis of biological control lies in the dynamic interactions among pests, their natural enemies, and the surrounding environment. Such interactions are influenced by climatic conditions, cropping systems, and landscape complexity.

The importance of biological control has been widely recognized in sustainable agriculture due to its long-term effectiveness, environmental safety, and compatibility with other pest management practices (Bale et al., 2008).

Classification of Biological Control Agents
1. Predators: Predators are free-living organisms that actively hunt, capture, and consume multiple prey individuals throughout their life cycle. They are generally larger than their prey and exhibit high feeding rates. Common predatory groups include coleopterans such as ladybird beetles, neuropterans such as lacewings, hemipterans like assassin bugs, and arachnids such as spiders.

Predators are particularly effective in controlling soft-bodied insect pests including aphids, whiteflies, thrips, and caterpillars. Their generalist feeding behavior allows them to adapt to varying pest populations, thereby providing consistent pest suppression across different cropping systems. Moreover, predators respond rapidly to increases in prey density, making them crucial in preventing pest outbreaks. However, their lack of host specificity may sometimes limit their effectiveness in targeting specific pests (Riddick, 2022).

2. Parasitoids: Parasitoids are specialized insects whose immature stages develop on or within a single host organism, ultimately leading to the host's death. They are predominantly found among the orders Hymenoptera and Diptera. Parasitoids exhibit high host specificity, making them ideal candidates for targeted pest control.

The life cycle of parasitoids is intricately synchronized with that of their hosts. Female parasitoids lay eggs inside or on the host, and the developing larvae consume host tissues. This precise host–parasitoid interaction ensures efficient pest suppression without affecting non-target organisms. Parasitoids are widely used in the management of lepidopteran, dipteran, and hemipteran pests.

Their effectiveness is influenced by environmental factors such as temperature, humidity, and availability of hosts. Additionally, their success depends on behavioural adaptations such as host-searching efficiency and reproductive capacity.

3. Pathogens (Entomopathogens): Entomopathogens include microorganisms such as bacteria, fungi, viruses, and nematodes that infect and kill insect pests. These biological agents are highly specific and can cause disease outbreaks within pest populations under favourable environmental conditions.

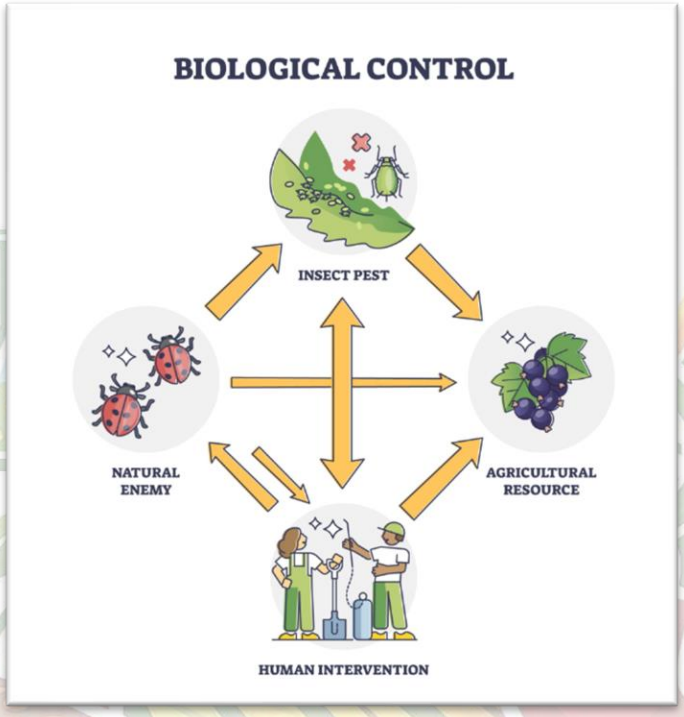
Bacterial agents such as *Bacillus thuringiensis* produce toxins that disrupt the digestive system of insects. Fungal pathogens infect pests through the cuticle, leading to systemic infections. Viral agents such as nucleopolyhedroviruses

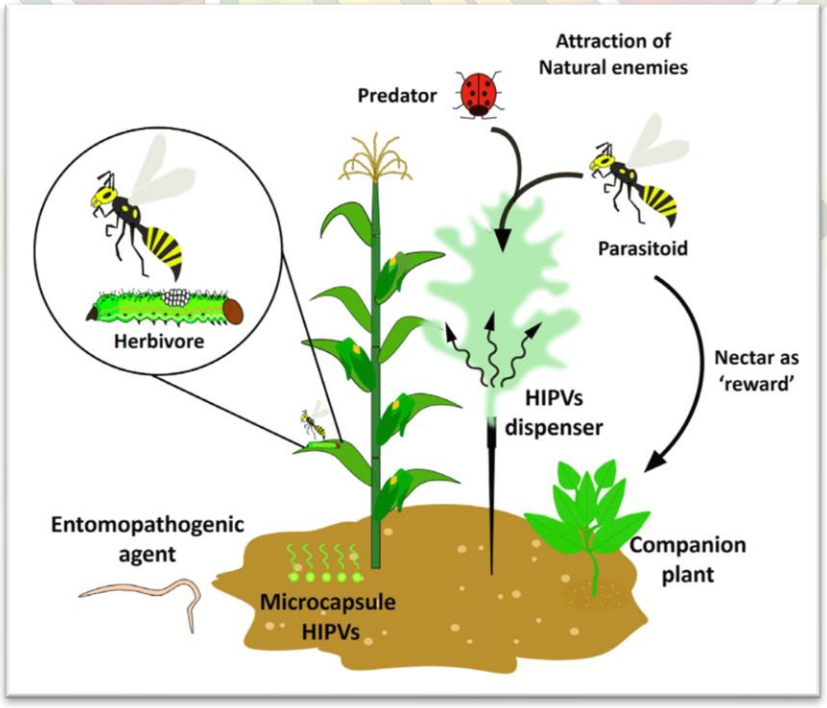
are particularly effective against lepidopteran larvae. Entomopathogenic nematodes actively seek out hosts and release symbiotic bacteria that cause rapid mortality.

The use of microbial biocontrol agents has gained significant importance due to their safety, specificity, and compatibility with IPM programs. However, their effectiveness is often influenced by environmental conditions such as temperature, humidity, and UV radiation.

4. Competitors and Herbivores in Weed Biological Control: Biological control is not limited to insect pests but also extends to weed management. Competitive organisms and herbivorous insects are used to suppress invasive weed species. These agents reduce weed vigour by feeding on plant tissues or competing for nutrients and space.

Weed biological control has been successfully implemented in several ecosystems, particularly in the management of invasive species. The selection of appropriate agents requires careful evaluation to avoid unintended ecological consequences.





Mechanisms of Pest Suppression by Natural Enemies

Natural enemies suppress pest populations through a variety of ecological and physiological mechanisms. Predation and parasitism directly reduce pest density by removing individuals from the population. Pathogens induce disease, leading to widespread mortality within pest populations.

Chemical ecology plays a crucial role in enhancing the efficiency of natural enemies. Plants under herbivore attack release volatile organic compounds that attract predators and parasitoids. These herbivore-induced plant volatiles act as signals, enabling natural enemies to locate their hosts more effectively.

Density-dependent regulation is another important mechanism, where the effectiveness of natural enemies increases with pest population density. This self-regulating system ensures long-term stability of agroecosystems. Additionally, behavioural and physiological adaptations of natural enemies contribute to their success in diverse environmental conditions (Thompson et al., 2022).

Factors Influencing Resistance Development

1. Classical Biological Control: Classical biological control involves the introduction of natural enemies from a pest's native range into areas where the pest has become invasive. This approach aims to re-establish ecological balance by restoring natural predator–prey relationships. Once established, these agents can provide permanent control with minimal human intervention.

2. Augmentative Biological Control: Augmentative biological control involves the mass production and release of natural enemies to enhance their population in the field. This approach is particularly useful in intensive agricultural systems where natural enemy populations are insufficient to control pests effectively. Inoculative releases involve the periodic introduction of small numbers of natural enemies to establish populations, whereas inundative releases involve the application of large numbers for immediate pest suppression.

3. Conservation Biological Control: Conservation biological control focuses on protecting and enhancing existing natural enemy populations. This can be achieved through habitat management practices such as maintaining floral diversity, reducing pesticide use, and providing refuges for beneficial organisms.

Agroecological practices such as intercropping, crop rotation, and conservation tillage contribute significantly to the conservation of natural enemies. These practices improve habitat quality and provide alternative food sources, thereby enhancing the effectiveness of biological control (Rusch et al., 2010).



Role of Natural Enemies in Integrated Pest Management (IPM)

Natural enemies are central to Integrated Pest Management, which integrates biological, cultural, mechanical, and chemical methods to achieve sustainable pest control. Biological control reduces reliance on chemical pesticides, thereby minimizing environmental contamination and the development of pesticide resistance.

In IPM systems, natural enemies provide long-term pest suppression and contribute to ecosystem resilience. Their integration requires careful monitoring, correct identification of pest and natural enemy species, and judicious use of pesticides to avoid negative impacts on beneficial organisms. The compatibility of biological control with other IPM components makes it a key strategy for sustainable agriculture (Bale et al., 2008).

Ecological and Environmental Significance

Biological control contributes significantly to ecosystem services, including pest regulation, biodiversity conservation, and maintenance of ecological balance. Natural enemies play a vital role in sustaining agricultural productivity by preventing excessive pest damage. The effectiveness of biological control is influenced by landscape complexity and habitat diversity. Agroecosystems with higher biodiversity tend to support greater populations of natural enemies, leading to improved pest suppression.

Furthermore, biological control reduces the environmental footprint of agriculture by decreasing pesticide use and preserving soil and water quality. It also enhances resilience to climate change by promoting stable and diversified ecosystems.

Advantages of Biological Control

Biological control offers numerous advantages, including environmental safety, target specificity, and sustainability. It reduces pesticide residues in food and the environment and lowers production costs over time. Additionally, biological control supports biodiversity conservation and promotes ecological stability. Unlike chemical control, it does not lead to resistance development in pests, making it a reliable long-term solution.

Limitations and Challenges

Despite its benefits, biological control faces several limitations. Its effectiveness is often slower compared to chemical pesticides, and it is highly dependent on environmental conditions. The success of biological control programs requires a thorough understanding of ecological interactions and careful selection of agents. Mass production, storage, and transportation of biological control agents pose logistical challenges. Furthermore, improper use of pesticides can negatively impact natural enemy populations, reducing their effectiveness. Non-target effects and ecological risks must also be carefully evaluated to ensure the safety of biological control programs.

Future Prospects and Emerging Trends

Advances in molecular biology, genomics, and biotechnology are opening new avenues for improving biological control agents. The use of genetic tools for strain improvement, along with artificial intelligence for pest monitoring, is expected to enhance the efficiency of biological control systems. Climate-smart agricultural practices and precision farming technologies are likely to further integrate biological control into sustainable farming systems. The development of biopesticides and improved mass-rearing techniques will also contribute to the wider adoption of biological control.

Conclusion

Biological control agents, particularly natural enemies, play a crucial role in sustainable pest management. Their ability to regulate pest populations, maintain ecological balance, and reduce dependence on chemical pesticides makes them indispensable in modern agriculture. The successful implementation of biological control requires a comprehensive understanding of ecological interactions, proper integration into IPM systems, and continuous research and innovation. With growing environmental concerns and the need for sustainable agriculture, biological control is poised to play an increasingly important role in global food security.

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Insect Pollinators and Ecosystem Services Conservation and Management

Article ID: 73541

Nicky Bansod[1], Dr.Punam Madavi[2], Shri. A. N. Surpam[3], Dr.V. D. Tayade[4]

[1]Assistant Professor of Agril. Entomology, SVGI, College of Agriculture, Jalgaon, Jamod, Maharashtra.

[2]Assistant Professor (C) of Agril. Entomology, Bhausaheb Fundkar Government College of Agriculture, Buldhana, Maharashtra.

[3]Junior Research Assistant, Bhausaheb Fundkar Government College of Agriculture, Buldhana (Dr. PDKV., Akola), Maharashtra.

[4]Assistant Professor (C) of Horticulture, Bhausaheb Fundkar Government College of Agriculture, Buldhana, Maharashtra.

Abstract

Insect pollinators constitute a cornerstone of terrestrial ecosystems, playing an indispensable role in plant reproduction, biodiversity maintenance, and global food security. Their contributions extend beyond pollination to include broader ecosystem services such as supporting trophic interactions, enhancing genetic diversity, and maintaining ecological resilience. However, increasing anthropogenic pressures including habitat loss, climate change, pesticide use, and invasive species are causing alarming declines in pollinator populations worldwide. This review synthesizes current knowledge on the diversity and ecological significance of insect pollinators, their role in ecosystem services, major threats affecting them, and strategies for their conservation and sustainable management. Emphasis is placed on integrating ecological, agricultural, and policy perspectives to safeguard pollinator populations and ensure the sustainability of ecosystem services essential for human well-being.

Introduction

Insect pollinators represent one of the most vital functional groups within terrestrial ecosystems, contributing significantly to ecological stability, agricultural productivity, and biodiversity conservation. Pollination is a fundamental ecological process that enables sexual reproduction in flowering plants through the transfer of pollen from anthers to stigmas. A substantial proportion of angiosperms rely on biotic pollination, particularly by insects, for successful fertilization and seed formation. It is estimated that nearly three-quarters of globally important crop species depend to varying degrees on animal-mediated pollination, underscoring the economic and nutritional significance of insect pollinators in sustaining food systems (Klein et al., 2007).

The role of insect pollinators extends beyond agricultural landscapes into natural ecosystems, where they maintain plant diversity, ensure gene flow, and contribute to ecosystem resilience. In recent decades, however, a marked decline in pollinator populations has been observed across different regions of the world, raising serious concerns about the long-term sustainability of ecosystem services and global food security (IPBES, 2016). These declines are attributed to a complex interplay of anthropogenic and environmental stressors, necessitating comprehensive research and management strategies.

Diversity and Functional Roles of Insect Pollinators

Insect pollinators comprise a taxonomically diverse group, including bees, butterflies, moths, beetles, flies, and wasps, each contributing uniquely to pollination dynamics. Among these, bees are considered the most efficient pollinators due to their morphological adaptations such as branched body hairs and specialized pollen-carrying structures. Both managed species such as *Apis mellifera* and a wide array of wild bee species play crucial roles in crop and wild plant pollination.

Butterflies and moths contribute to pollination through their long proboscis, enabling them to access nectar from deep floral structures, while flies, particularly hoverflies, are significant pollinators in cooler climates and high-altitude ecosystems. Beetles, often regarded as primitive pollinators, are important for certain plant taxa, especially those with large and robust flowers. This diversity of pollinators ensures functional redundancy and complementarity, which enhances pollination efficiency under variable environmental conditions.

Functional diversity among pollinators is critical for ecosystem stability, as different species exhibit variations in foraging behavior, temporal activity patterns, and habitat preferences. Such diversity allows ecosystems to maintain pollination services even under environmental disturbances. Studies have demonstrated that ecosystems with higher pollinator diversity exhibit improved plant reproductive success and resilience to environmental changes (Ollerton et al., 2011). Furthermore, wild pollinators often outperform managed species in certain crops, highlighting their indispensable role in sustaining ecosystem services.

Ecosystem Services Provided by Insect Pollinators

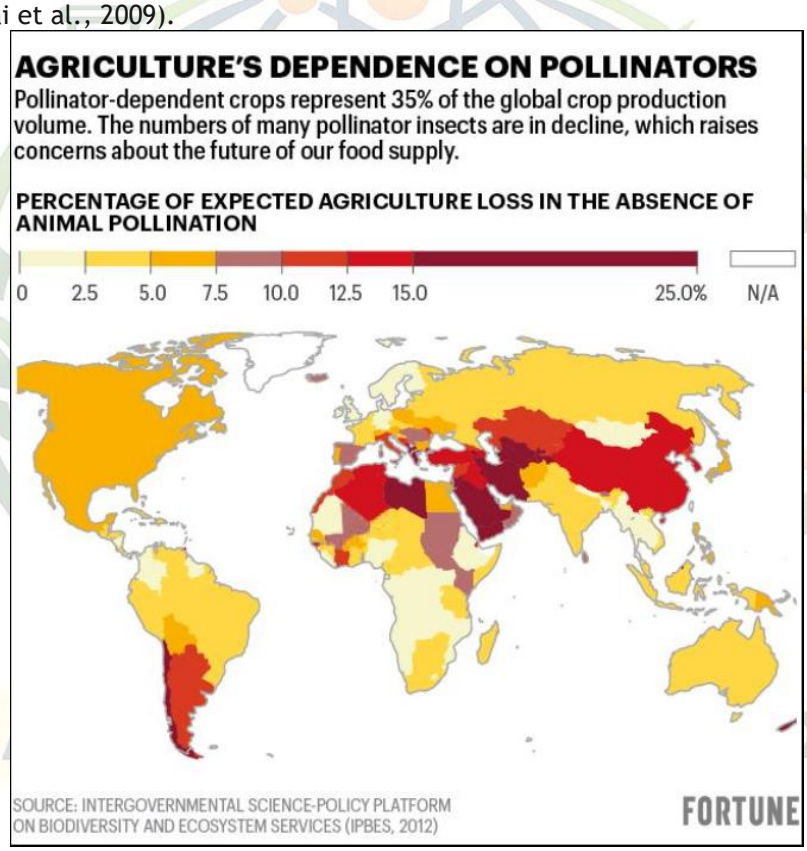
Insect pollinators contribute to multiple categories of ecosystem services, which are essential for ecological balance and human well-being. Their role in provisioning services is evident in the production of fruits, vegetables, nuts, and seeds, many of which are integral to human nutrition. Pollination enhances not only crop yields but also the quality attributes of produce, including size, shape, and nutritional composition.

In terms of regulating services, insect pollinators facilitate plant reproduction and regeneration, which in turn supports carbon sequestration and climate regulation. By maintaining plant diversity, pollinators indirectly contribute to soil stabilization, water regulation, and habitat provision for other organisms. Their interactions with plant communities also influence ecosystem structure and function.

Supporting services provided by pollinators include the maintenance of genetic diversity through cross-pollination, which is essential for the adaptability and evolution of plant species. This genetic exchange enhances plant resistance to diseases and environmental stressors, thereby contributing to long-term ecosystem sustainability.

Cultural ecosystem services associated with insect pollinators encompass their aesthetic, educational, and recreational value. Butterflies and bees are widely appreciated for their beauty and ecological significance, contributing to ecotourism and environmental awareness. Pollinators also hold cultural and symbolic importance in many societies.

The economic valuation of pollination services highlights their immense contribution to global agriculture. Pollinators are responsible for a significant portion of agricultural output, and their decline could result in substantial economic losses. Quantitative assessments have demonstrated that pollination services contribute billions of dollars annually to the global economy (Gallai et al., 2009).



Drivers of Pollinator Decline

The decline of insect pollinators is driven by a combination of anthropogenic and environmental factors that act synergistically to reduce pollinator populations and impair their functioning. Habitat loss and fragmentation due to agricultural expansion, urbanization, and deforestation have led to a reduction in floral resources and nesting sites, thereby limiting pollinator survival and reproduction.

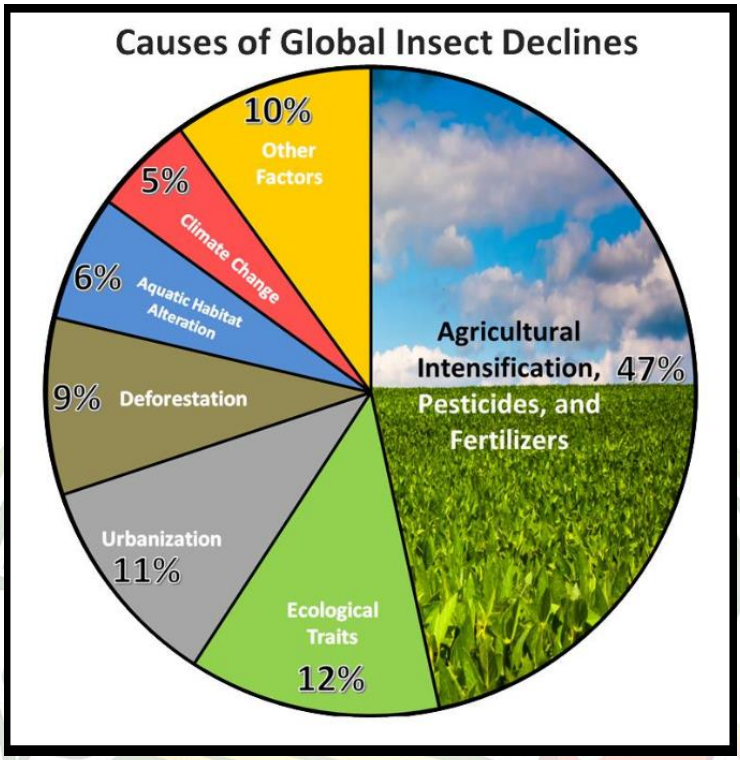
The widespread use of pesticides, particularly neonicotinoids, has been identified as a major factor contributing to pollinator decline. These chemicals can have lethal and sub-lethal effects on pollinators, affecting their foraging behavior, navigation, and reproductive success. Chronic exposure to pesticides can weaken pollinator populations and increase their susceptibility to diseases.

Climate change poses another significant threat by altering temperature and precipitation patterns, which can disrupt the synchrony between flowering plants and their pollinators. Phenological mismatches can reduce pollination efficiency

and negatively impact plant reproduction. Additionally, extreme weather events such as droughts and heatwaves can directly affect pollinator survival.

The introduction of invasive species and the spread of pathogens further exacerbate pollinator declines. Invasive plants can outcompete native flora, reducing the availability of suitable food resources for pollinators. Similarly, parasites and diseases can spread rapidly within pollinator populations, leading to colony collapse and population declines.

Environmental pollution, including air pollution and heavy metals, can impair pollinator health and disrupt plant-pollinator interactions. Pollutants can alter floral scent signals, making it difficult for pollinators to locate flowers, thereby reducing pollination success.



Conservation Strategies for Insect Pollinators

The conservation of insect pollinators requires a multifaceted approach that integrates ecological, agricultural, and policy-based interventions. Habitat restoration and enhancement are fundamental to pollinator conservation, involving the establishment of flower-rich habitats, hedgerows, and buffer strips within agricultural landscapes. These habitats provide essential resources such as nectar, pollen, and nesting sites.

Sustainable agricultural practices play a crucial role in reducing the negative impacts of farming on pollinators. The adoption of integrated pest management strategies, organic farming, crop diversification, and reduced pesticide use can create a more favourable environment for pollinators. Agroecological approaches that promote biodiversity within farming systems are particularly effective in enhancing pollinator populations.

The conservation of wild pollinators is equally important, as they provide complementary and often irreplaceable ecosystem services. Protecting natural habitats, conserving native plant species, and minimizing disturbances are essential for maintaining wild pollinator diversity.

Policy interventions and institutional frameworks are critical for supporting pollinator conservation. Governments and international organizations have initiated various programs and policies aimed at protecting pollinators, including regulations on pesticide use and incentives for pollinator-friendly practices. The integration of pollinator conservation into national biodiversity strategies is essential for long-term sustainability.

Community participation and public awareness are key components of successful conservation efforts. Educating farmers, stakeholders, and the general public about the importance of pollinators and the threats they face can promote the adoption of conservation practices and foster a sense of stewardship.

Management Approaches for Enhancing Pollination Services

Effective management of pollination services involves both ecological and technological approaches aimed at optimizing pollinator populations and their functioning. Managed pollination using domesticated species such as honey bees and bumble bees is widely practiced in agricultural systems to enhance crop productivity. However, reliance on managed pollinators should be balanced with efforts to conserve wild pollinators.

Landscape-level management strategies that integrate natural habitats within agricultural landscapes are essential for maintaining pollinator diversity and ecosystem stability. The creation of ecological corridors and the preservation of semi-natural habitats can facilitate pollinator movement and gene flow.

Technological innovations are increasingly being used to monitor and manage pollinator populations. Advances in remote sensing, geographic information systems, and artificial intelligence have enabled more precise assessment of pollinator habitats and their dynamics. These tools can support decision-making processes and improve the effectiveness of conservation strategies.

Integrated pollinator management approaches that combine ecological principles with modern agricultural practices offer a holistic solution for sustaining pollination services. Such approaches emphasize the conservation of biodiversity, the reduction of chemical inputs, and the enhancement of ecosystem resilience.

Future Perspectives and Research Needs

Despite significant progress in understanding pollinator ecology, several knowledge gaps remain. Future research should focus on quantifying the contributions of different pollinator species to ecosystem services, understanding the impacts of multiple stressors on pollinator health, and developing climate-resilient pollination systems. There is also a need for interdisciplinary research that integrates ecological, economic, and social dimensions of pollinator conservation.

The development of sustainable agricultural systems that support pollinator diversity is essential for ensuring long-term food security. Innovations in agroecology, biotechnology, and digital agriculture hold promise for enhancing pollinator conservation and management.

Conclusion

Insect pollinators are indispensable for maintaining ecosystem services that underpin biodiversity, agricultural productivity, and human well-being. The decline of pollinator populations poses a significant threat to ecological stability and food security. Addressing this challenge requires coordinated efforts at local, national, and global levels, involving scientific research, policy interventions, and community engagement. By adopting sustainable practices and promoting pollinator conservation, it is possible to safeguard these vital ecosystem service providers for future generations.

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Insect-Borne Diseases in Agriculture Epidemiology and Control

Article ID: 73542

Dr. Sudipta Padhan[1], Trishna Mahto[2], Sabba Parween[3], Oroba Adan[4]

[1]Assistant Professor cum Junior Scientist, Department of Plant Protection (Entomology), Horticulture. College, Khuntpani, Chaibasa, (Birsa Agricultural University, Ranchi), Jharkhand.

[2,3,4]Student, Horticulture College, Khuntpani, Chaibasa, (Birsa Agricultural University, Ranchi), Jharkhand.

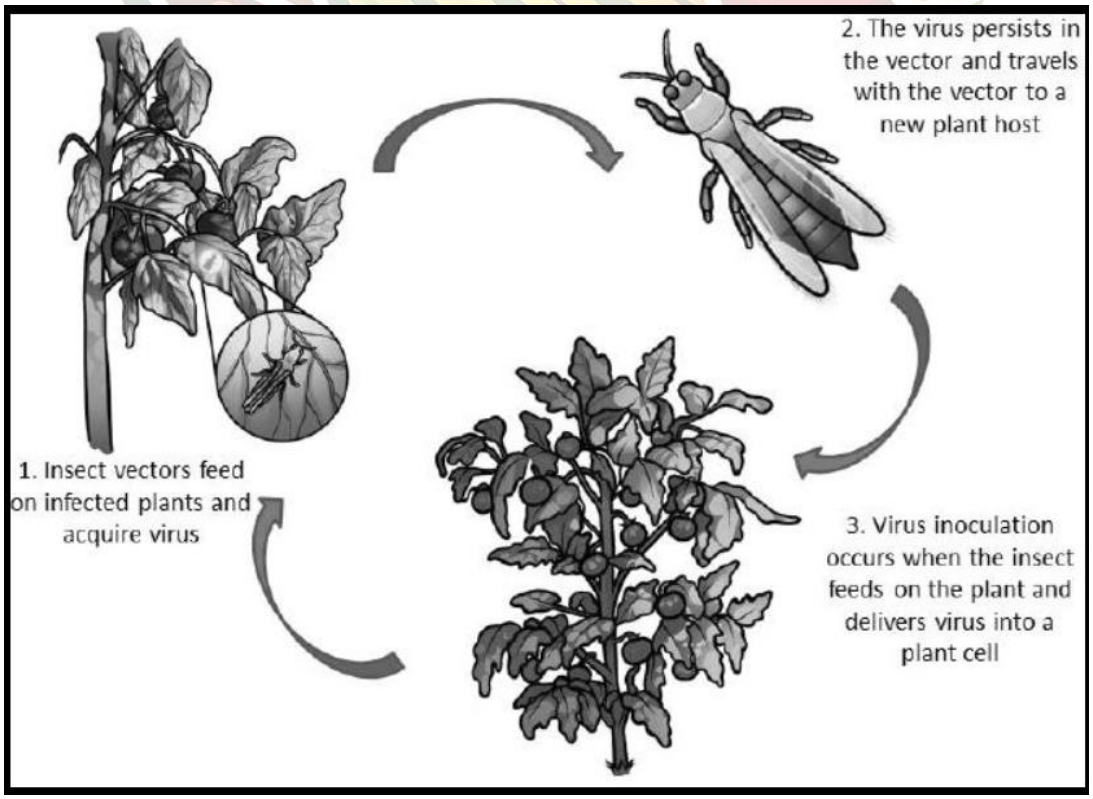
Abstract

Insect-borne diseases are among the most significant biological constraints affecting global agricultural productivity, leading to severe yield losses, deterioration in crop quality, and economic instability. These diseases arise from intricate interactions among insect vectors, plant hosts, and a wide range of pathogens, including viruses, bacteria, phytoplasmas, and certain fungi. The epidemiology of such diseases is highly dynamic and influenced by environmental factors, vector population biology, cropping systems, and anthropogenic activities. With the ongoing challenges of climate change, globalization, and agricultural intensification, the emergence and re-emergence of insect-borne diseases have intensified. Effective management requires a holistic understanding of disease ecology, transmission mechanisms, and integrated control strategies. This review provides a detailed and expanded analysis of insect-borne diseases in agriculture, focusing on epidemiological principles, vector-pathogen interactions, and sustainable management approaches.

Introduction

Insect-borne diseases constitute a major category of plant diseases in which pathogens are transmitted from infected to healthy plants by insect vectors. These diseases are particularly important in tropical and subtropical agriculture, including India, where favourable climatic conditions support year-round vector activity. Unlike soil- or seed-borne diseases, insect-mediated transmission enables rapid and long-distance dissemination, often resulting in explosive epidemics.

Insects such as aphids, whiteflies, leafhoppers, planthoppers, thrips, psyllids, and beetles serve as vectors due to their feeding habits, especially phloem feeding. These insects possess specialized mouthparts that allow efficient uptake and transmission of pathogens. Viral diseases dominate insect-borne plant diseases, with aphids alone responsible for transmitting more than 200 plant viruses (Nault 1997). The increasing importance of insect-borne diseases is closely linked to agricultural intensification, monoculture practices, and climate variability, all of which enhance vector survival and disease transmission.

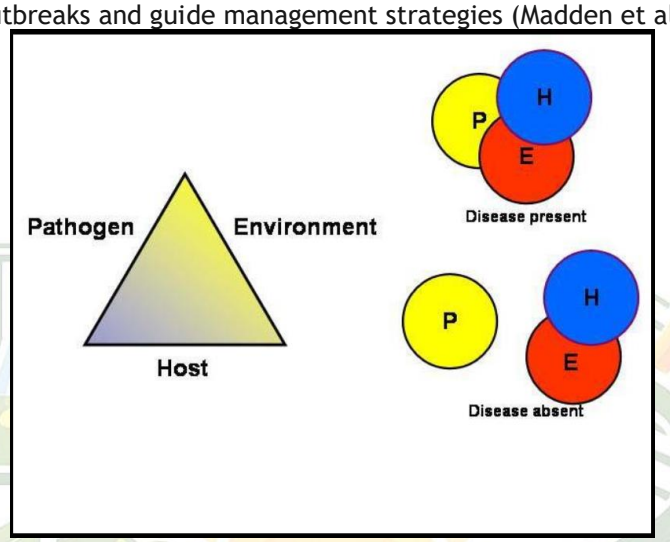


Concept and Scope of Epidemiology in Insect-Borne Diseases

Epidemiology in plant pathology deals with the study of disease occurrence, distribution, and spread in plant populations over time and space. In insect-borne diseases, epidemiology becomes more complex due to the involvement of an additional biological component—the vector.

The classical disease triangle (host–pathogen–environment) expands into a disease tetrahedron with the inclusion of the vector. The vector acts not only as a carrier but also as a biological host in many cases, influencing pathogen survival, multiplication, and transmission efficiency.

Key epidemiological parameters include infection rate, vector density, dispersal ability, latent period, incubation period, and transmission efficiency. Temporal dynamics such as primary and secondary infection cycles play crucial roles in epidemic development. Spatial epidemiology considers disease gradients, dispersal patterns, and landscape-level influences. Advanced epidemiological approaches now incorporate geospatial tools, remote sensing, and predictive modelling to forecast disease outbreaks and guide management strategies (Madden et al. 2007).



Diversity of Insect Vectors and their Agricultural Importance

Insect vectors differ in their biology, feeding behaviour, and transmission mechanisms, which significantly influence disease epidemiology.

1. Aphids (Hemiptera: Aphididae) are among the most efficient vectors due to their rapid reproduction, polyphagy, and ability to transmit viruses in a non-persistent manner. Their probing behavior allows rapid acquisition and inoculation of viruses within seconds.

2. Whiteflies, particularly *Bemisia tabaci*, are globally important vectors of begomoviruses. Their persistent transmission mechanism and ability to colonize diverse host plants make them highly destructive.

3. Leafhoppers and planthoppers transmit phytoplasmas and viruses affecting major crops like rice, sugarcane, and vegetables. These vectors often exhibit host specificity and long-distance migration.

4. Thrips transmit tospoviruses in a propagative manner, meaning the virus replicates within the vector, increasing transmission efficiency.

5. Psyllids are vectors of bacterial pathogens such as *Candidatus Liberibacter*, responsible for citrus greening disease, one of the most devastating diseases in horticulture.

6. Beetles and other chewing insects also contribute to pathogen transmission, especially bacterial and fungal pathogens, through mechanical means.

Pathogen Diversity and Host-Vector-Pathogen Interactions

1. Viral Pathogens: Plant viruses are the most prevalent insect-transmitted pathogens. They exhibit diverse transmission modes and host ranges. Viral replication within host plants disrupts physiological processes, leading to symptoms such as mosaic patterns, chlorosis, stunting, and yield reduction.

2. Bacterial Pathogens: Bacterial pathogens transmitted by insects often colonize vascular tissues. For example, *Xylella fastidiosa* inhabits xylem vessels, while *Candidatus Liberibacter* resides in phloem tissues. These pathogens can persist within vectors, enhancing transmission efficiency.

3. Phytoplasmas and Mollicutes: Phytoplasmas are obligate parasites lacking cell walls, transmitted primarily by leafhoppers. They induce severe morphological abnormalities such as witches' broom, phyllody, and little leaf symptoms.

4. Fungal Associations: Although less common, certain fungi are associated with insect transmission, often facilitated by wounds created during feeding. Host–vector–pathogen interactions involve complex molecular signalling. Pathogens can manipulate vector behaviour and plant physiology to enhance transmission. For instance, infected plants may emit volatile compounds that attract vectors, facilitating disease spread.

Mechanisms of Pathogen Transmission and Retention

1. Transmission mechanisms determine the epidemiological characteristics of insect-borne diseases.

2. Non-persistent transmission involves rapid acquisition and inoculation without pathogen replication within the vector. This mode leads to rapid but short-lived transmission.

3. Semi-persistent transmission involves longer retention of pathogens but no replication within the vector.

4. Persistent transmission is subdivided into circulative and propagative types. In circulative transmission, the pathogen circulates within the vector body without replication. In propagative transmission, the pathogen replicates within the vector, increasing transmission potential.

5. The duration of pathogen retention, known as the retention period, plays a crucial role in epidemic development. Vectors with longer retention periods contribute to sustained disease spread.

Epidemiological Determinants of Disease Development

1. Vector Ecology and Population Dynamics: Vector abundance, reproduction rate, survival, and dispersal behavior directly influence disease incidence. Environmental factors such as temperature and humidity significantly affect vector biology.

2. Host Plant Resistance and Susceptibility: Genetic resistance in host plants can reduce disease incidence by limiting pathogen multiplication or vector feeding. However, resistance breakdown due to pathogen evolution remains a challenge.

3. Environmental and Climatic Factors: Temperature influences vector metabolism and pathogen replication. Increased temperatures often accelerate vector life cycles and expand their geographical distribution. Climate change has facilitated the emergence of new insect-borne diseases in previously unaffected regions (Jones 2016).

4. Cropping Systems and Agricultural Practices: Monocropping, high-density planting, and continuous cropping favor vector proliferation and disease spread. Conversely, diversified cropping systems and intercropping can reduce disease incidence.

5. Landscape Ecology: The presence of alternate hosts, weed reservoirs, and ecological corridors influences disease dynamics. Landscape-level management is increasingly recognized as essential for disease control.

Disease Cycles and Epidemic Development

The disease cycle begins with the acquisition of the pathogen by the vector from infected plants. After a latent period, the vector becomes infective and transmits the pathogen to healthy plants. Secondary spread occurs through vector movement within and between fields. Epidemics are influenced by primary inoculum sources, vector activity, and environmental conditions. Disease progress curves typically follow sigmoid patterns, reflecting slow initial spread followed by rapid epidemic growth and eventual stabilization. Mathematical models such as logistic and Gompertz models are used to describe disease progress and predict epidemic outcomes (Madden et al. 2007).

Impact on Agricultural Productivity and Food Security

Insect-borne diseases can cause yield losses ranging from 20% to complete crop failure under severe conditions. For example, tomato yellow leaf curl disease and rice tungro disease have caused devastating losses in Asia and Africa. Economic impacts include increased production costs due to pest management, reduced market value, and trade restrictions. In developing countries, these diseases pose a serious threat to food security and farmer livelihoods.

Integrated Disease Management Strategies

1. Cultural and Agronomic Practices: Cultural practices such as crop rotation, removal of infected plants (roguing), adjustment of planting dates, and intercropping reduce disease incidence by disrupting vector life cycles.

2. Host Plant Resistance: Breeding for resistance remains one of the most sustainable approaches. Advances in molecular breeding and genetic engineering have enabled the development of resistant cultivars.

3. Chemical Control: Insecticides are widely used to control vectors. However, indiscriminate use leads to resistance development, environmental contamination, and non-target effects.

4. Biological Control: Natural enemies such as predators, parasitoids, and entomopathogenic microorganisms play a crucial role in regulating vector populations. Conservation biological control strategies enhance their effectiveness.

5. Integrated Pest Management (IPM): IPM integrates multiple control strategies based on ecological principles. It emphasizes monitoring, threshold-based interventions, and minimal use of chemicals.

6. Advanced Technologies: Modern approaches include RNA interference (RNAi), CRISPR-based resistance, use of semiochemicals, and digital agriculture tools such as remote sensing and AI-based disease forecasting systems.

Emerging Challenges and Future Directions

The emergence of new insect-borne diseases due to climate change, globalization, and pathogen evolution poses significant challenges. Future research should focus on understanding molecular interactions, developing climate-resilient management strategies, and integrating advanced technologies into disease management systems. The adoption of precision agriculture and data-driven decision-making will enhance the efficiency and sustainability of disease control.

Conclusion

Insect-borne diseases represent a complex and evolving challenge in agriculture. Their epidemiology is governed by multifaceted interactions among vectors, pathogens, hosts, and environmental factors. Effective management requires an integrated and sustainable approach combining cultural, biological, chemical, and genetic strategies. Continued research and technological advancements are essential to mitigate the impact of these diseases and ensure global food security.

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Climate Change Impacts on Insect Ecology and Distribution

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Dr. Sudipta Padhan[1], Arpit Srivastava[2], Amisha Pratap[3], Vaishnavi Prasad[4], Dhiraj Mahato[5], Aniket Tanmay Tirkey[6]

[1]Assistant Professor cum Junior Scientist, Department of Plant Protection (Entomology), Horticulture College, Khuntpani, Chaibasa, (Birsa Agricultural University, Ranchi), Jharkhand.

[2,3,4,5,6]Student, Horticulture College, Khuntpani, Chaibasa, (Birsa Agricultural University, Ranchi), Jharkhand.

Abstract

Climate change is profoundly altering biological systems across the globe, with insects among the most responsive taxa due to their ectothermic physiology and rapid life cycles. Variations in temperature, precipitation, and atmospheric composition are influencing insect development, survival, reproduction, and dispersal. These changes are driving significant shifts in insect phenology, geographic distribution, and species interactions, ultimately reshaping ecosystem processes and services. Climate-induced alterations in insect populations are particularly critical for agriculture, where increased pest outbreaks and disrupted pollination systems threaten food security. This review provides a comprehensive synthesis of current knowledge on how climate change affects insect ecology and distribution, integrating physiological, ecological, and evolutionary perspectives, and highlighting future research priorities.

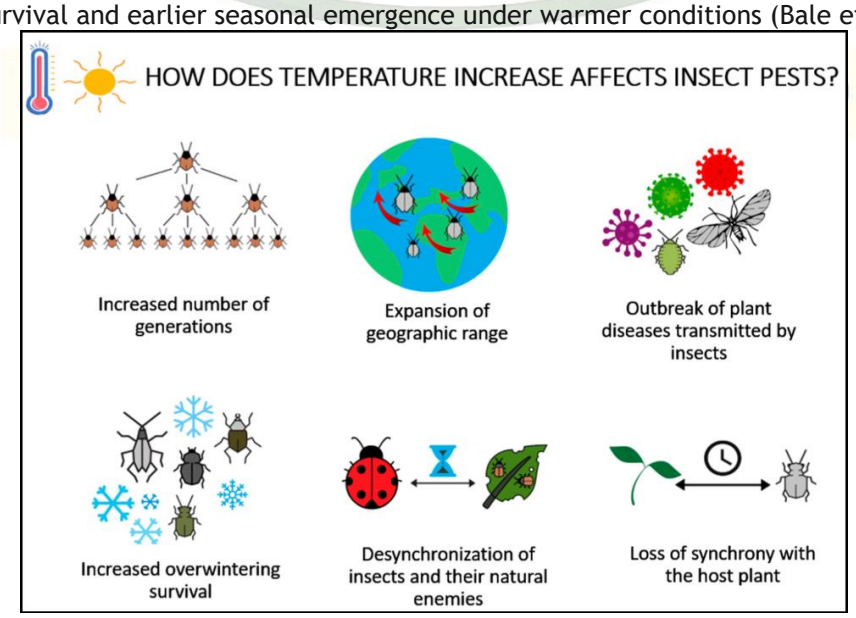
Introduction

Insects represent the most diverse and ecologically significant group of organisms, accounting for more than half of all known living species. Their roles in pollination, decomposition, herbivory, and biological control make them integral to ecosystem functioning. However, their close dependence on environmental conditions renders them highly sensitive to climatic fluctuations.

Recent decades have witnessed unprecedented changes in global climate patterns, characterized by rising temperatures, altered precipitation regimes, and increased frequency of extreme weather events. These changes are already influencing insect populations at multiple biological levels, from molecular and physiological processes to community dynamics and biogeographical patterns. Evidence from long-term datasets suggests that insect responses to climate change are often rapid and measurable, making them valuable bioindicators of environmental change (Parmesan et al., 2006).

Climatic Drivers and their Multifaceted Influence

1. Temperature as a Master Regulator: Temperature governs nearly all aspects of insect life, including metabolic rate, enzyme activity, development time, and reproductive success. According to thermal performance theory, insect physiological processes increase with temperature up to an optimum threshold, beyond which performance declines sharply. Warming trends have resulted in accelerated development rates, increased voltinism (number of generations per year), and extended activity periods in many insect species. For instance, several temperate insect pests have shown increased overwinter survival and earlier seasonal emergence under warmer conditions (Bale et al., 2002).

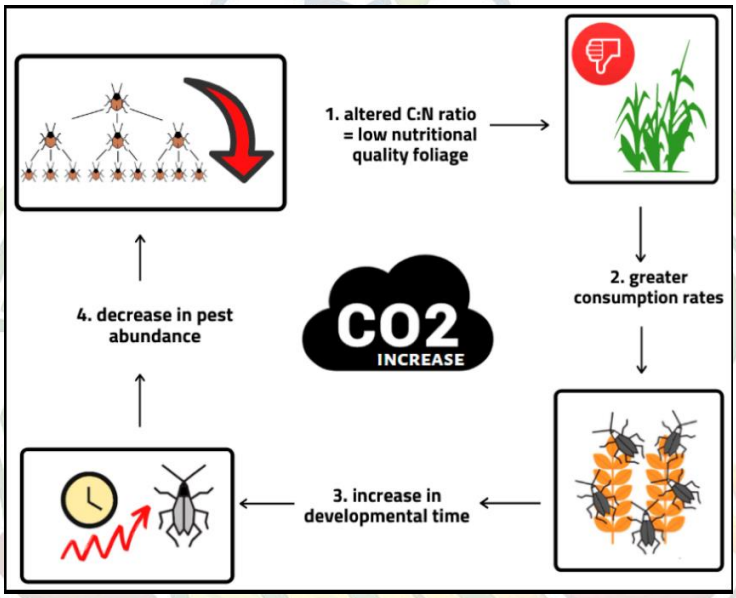


However, the benefits of warming are not universal. Extreme temperatures can exceed thermal tolerance limits, leading to protein denaturation, oxidative stress, and mortality. Heatwaves, in particular, can have catastrophic effects on insect populations, especially those lacking behavioural or physiological buffering mechanisms (Harvey et al., 2020).

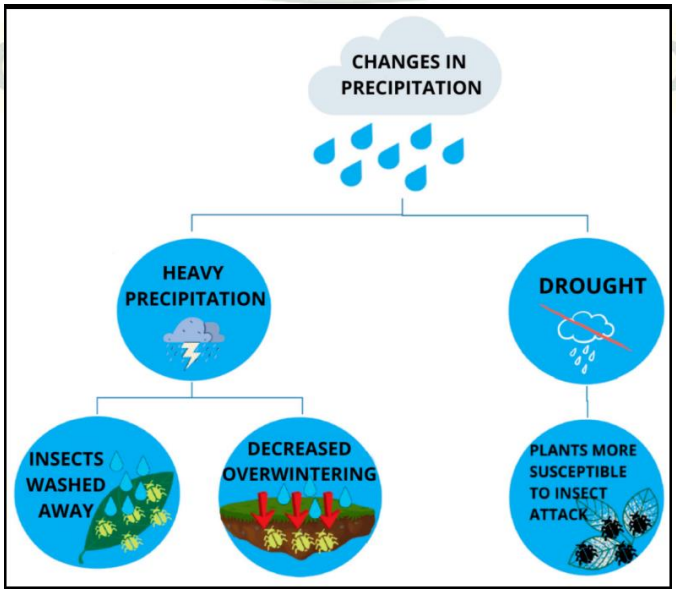
2. Altered Precipitation Patterns and Hydrological Stress: Changes in rainfall patterns influence insect ecology both directly and indirectly. Moisture availability affects egg survival, larval development, and adult activity. Increased rainfall can enhance habitat suitability for many insect vectors, while drought conditions can suppress populations by reducing host plant availability.

In agricultural systems, irregular precipitation can disrupt synchrony between pests and crops, sometimes reducing damage but often creating conditions for unexpected pest outbreaks. Soil moisture also plays a critical role in the survival of soil-dwelling insects and pupae.

3. Elevated CO_2 and Plant-Mediated Effects: Rising atmospheric carbon dioxide levels influence insect herbivores indirectly through changes in host plant physiology. Elevated CO_2 often leads to increased carbon-to-nitrogen ratios in plant tissues, reducing nutritional quality. In response, herbivorous insects may increase feeding rates to compensate for reduced nitrogen content, potentially leading to greater plant damage (Robinson et al., 2012). Additionally, changes in plant secondary metabolites under elevated CO_2 conditions can alter plant defence mechanisms, influencing herbivore performance and interactions with natural enemies.



4. Increased Frequency of Extreme Events: Climate change has intensified the occurrence of extreme weather events such as storms, floods, droughts, and heatwaves. These events can cause immediate mortality or long-term population changes by altering habitat structure and resource availability. Extreme events can also disrupt ecological stability by affecting species interactions. For example, a heatwave may disproportionately impact predators or parasitoids, allowing pest populations to surge unchecked.



Physiological and Developmental Responses

Climate change affects insect physiology at multiple levels, including metabolism, water balance, and thermal tolerance. Increased temperatures generally enhance metabolic rates, leading to faster growth and development. However, elevated metabolic demands may also increase susceptibility to stress under resource-limited conditions. Diapause regulation is particularly sensitive to climatic cues such as temperature and photoperiod. Climate-induced shifts in these cues can disrupt diapause timing, resulting in premature emergence or delayed development, both of which can reduce survival. Furthermore, insects may exhibit changes in body size, a phenomenon often described by the temperature–size rule, where individuals developing at higher temperatures tend to be smaller. Such changes can have cascading effects on fecundity, dispersal ability, and predator-prey interactions.

Phenological Changes and Ecological Mismatches

Climate warming has led to significant shifts in insect phenology, including earlier emergence, prolonged activity periods, and altered seasonal cycles. These changes can disrupt synchrony between interacting species, such as pollinators and flowering plants or predators and prey. Phenological mismatches can have severe ecological consequences. For example, if pollinators emerge before or after peak flowering periods, pollination efficiency may decline, affecting plant reproduction and crop yields. Similarly, mismatches between herbivores and host plants can influence survival and population dynamics. Long-term studies have demonstrated that phenological shifts are among the most consistent biological responses to climate change across taxa (Parmesan et al., 2006).

Shifts in Geographic Distribution

1. Poleward and Elevational Movement: One of the most well-documented effects of climate change is the redistribution of species toward higher latitudes and elevations. As temperatures rise, previously unsuitable habitats become accessible, enabling insects to expand their range.

Numerous studies have reported poleward shifts in butterfly and beetle distributions, as well as upward movement in mountainous regions. These shifts can lead to novel species interactions and altered community structures.

2. Invasive Species Expansion: Climate change facilitates the spread of invasive insect species by creating favourable conditions in new regions. Warmer climates can enhance establishment success, reproductive rates, and dispersal capacity. Invasive pests often lack natural enemies in new environments, leading to rapid population growth and significant ecological and economic impacts.

Range Contraction and Extinction Risks

While some species expand their ranges, others experience contraction due to habitat loss or inability to migrate. Species with limited dispersal ability or specialized ecological requirements are particularly vulnerable. High-altitude and polar species face increased extinction risks as their habitats shrink and suitable conditions become increasingly limited.

Population Dynamics and Pest Outbreaks

Climate change has complex effects on insect population dynamics. Increased temperatures can enhance reproductive rates and survival, leading to population growth. However, extreme conditions may also suppress populations. Agricultural pests are of particular concern, as climate change can increase the frequency and severity of outbreaks. For example, warmer winters can improve overwinter survival, while longer growing seasons provide more opportunities for reproduction. Nevertheless, responses are species-specific and influenced by interactions with other environmental factors, including host availability and natural enemies (Deutsch et al., 2008; Skendžić et al., 2021).

Trophic Interactions and Ecosystem Functioning

Climate change can disrupt complex trophic interactions involving plants, herbivores, predators, and parasitoids. Differential responses among trophic levels can lead to imbalances in ecological systems. For instance, if natural enemies are more sensitive to climate change than herbivores, pest populations may increase. Conversely, enhanced predator activity under warmer conditions may suppress some pest species. Pollination services are also affected, as climate-induced changes in pollinator behaviour and distribution can reduce pollination efficiency, impacting both wild ecosystems and agricultural production.

Implications for Agriculture and Food Security

The impacts of climate change on insect ecology have significant implications for agriculture. Increased pest pressure can lead to higher crop losses, reduced yields, and increased reliance on chemical pesticides. At the same time, disruptions in beneficial insect populations, including pollinators and natural enemies, can compromise ecosystem services essential for sustainable agriculture. In regions such as South Asia, where agriculture is highly climate-sensitive, these impacts pose serious challenges to food security and rural livelihoods.

Evolutionary Responses and Adaptive Potential

Insects possess considerable adaptive potential due to their short generation times and high reproductive rates. Evolutionary responses to climate change may include increased thermal tolerance, altered behaviour, and changes in life-history traits. Phenotypic plasticity allows insects to adjust to changing conditions without genetic change. However, the rapid pace of climate change may outstrip the adaptive capacity of many species, leading to population declines.

Knowledge Gaps and Future Research Needs

Despite growing evidence of climate change impacts on insects, significant knowledge gaps remain. There is a need for long-term, large-scale studies to understand cumulative effects and interactions among multiple stressors. Integrative approaches combining physiology, ecology, genomics, and modelling are essential for predicting future trends. Additionally, region-specific studies, particularly in tropical and developing regions, are crucial for developing effective management strategies.

Conclusion

Climate change is fundamentally altering insect ecology and distribution, with far-reaching consequences for ecosystems and human societies. While some species may benefit from warming conditions, many face increased risks due to habitat loss, disrupted interactions, and physiological stress. A comprehensive understanding of these changes is essential for developing adaptive management strategies aimed at conserving biodiversity, maintaining ecosystem services, and ensuring food security in a changing climate.

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Advancements in Cow Dung Dewatering and Sustainable Waste Management

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Shrvan Kumar[1], Aditya Gupta[3], Vicky Singh[3], Surush Das[2], Shradha Subba[2]
[1]Department of Mycology and Plant Pathology, [3]RGSC, Banaras Hindu University, Varanasi (U.P.), India.
[2] Plant Biotechnology Laboratory, RGSC, Banaras Hindu University, Varanasi (U.P.), India.

Abstract

Livestock farming produces large amounts of cow dung (10–20 kg per cow daily), with 75–85% moisture, making it bulky and polluting. Dewatering machines separate solid and liquid parts, improving handling, reducing odor, and enabling sustainable use. Cow dung extract is nutrient-rich (N, P, K and micronutrients) and enhances plant growth, increasing yields by 10–25%. It contains beneficial microbes like *Lactobacillus* and *Bacillus*, improving soil fertility and microbial biomass. It also acts as a natural biopesticide, reducing pathogens by 30–60%. Additionally, it improves soil structure, boosts water retention, supports carbon sequestration, and promotes eco-friendly farming practices like Jeevamrit.

Keywords: Cow dung, microbial biomass, soil structure, natural biopesticide and eco-friendly farming practices.

Introduction

Livestock farming, especially dairy farming, produces enormous quantities of cow dung daily. A single cow can generate approximately 10–20 kg of dung per day, depending on its diet, breed, and health condition. Fresh cow dung is primarily a slurry-like material containing a very high percentage of water, typically around 75–85% moisture. Cow dung is extremely valuable, especially in rural and agricultural systems. It's not just waste—it's a multi-purpose resource with economic, environmental, and practical benefits. This high water content makes the dung bulky, difficult to handle, and prone to rapid decomposition, which can lead to environmental pollution, foul odor, health hazards and the release of harmful greenhouse gases. To address these challenges, the cow dung dewatering machine has emerged as an efficient technological solution for sustainable waste management.

To overcome these challenges, the process of dewatering cow dung using machines has become an essential technological advancement in modern agriculture. Dewatering machines separate the solid and liquid components of dung, transforming it into a more manageable, resource-efficient, and environmentally friendly form. This technology plays a crucial role in waste management, organic farming, and renewable energy production.

From a scientific perspective, cow dung extract is rich in macro- and micronutrients. Studies show that fresh cow dung typically contains about 0.5–1.5% nitrogen (N), 0.2–0.8% phosphorus (P), and 0.5–1.0% potassium (K), along with trace elements such as zinc, copper, and iron. When converted into liquid extract, these nutrients become more readily available to plants, leading to improved nutrient uptake. Research in soil science indicates that application of such organic extracts can increase crop yields by 10–25%, depending on soil conditions and crop type.

One of the most important scientific aspects of cow dung extract is its microbial richness. It contains beneficial microorganisms such as *Lactobacillus*, *Bacillus*, and actinomycetes. These microbes play a critical role in biogeochemical cycles, particularly nitrogen fixation and organic matter decomposition. Scientific studies have shown that soils treated with cow dung-based formulations can exhibit up to 2–3 times higher microbial biomass carbon, which directly correlates with improved soil fertility and structure.

Cow dung extract also demonstrates biopesticidal properties. Experimental data suggest that foliar sprays made from cow dung extract can reduce the incidence of fungal pathogens like *Fusarium* and *Alternaria* by 30–60%. The antimicrobial effect is attributed to the presence of phenolic compounds, ammonia, and certain volatile fatty acids produced during fermentation. This reduces dependence on synthetic pesticides, lowering chemical residues in food and soil.

Another scientifically validated benefit is its role in improving soil physical properties. Regular application enhances soil porosity, water-holding capacity, and aeration. For example, field trials have reported an increase in soil water retention by 15–20%, which is particularly beneficial in drought-prone regions. Improved soil aggregation also reduces erosion and enhances root penetration.

In the context of environmental sustainability, cow dung extract contributes to carbon sequestration and reduced greenhouse gas emissions. Organic amendments increase soil organic carbon levels, which can rise by 0.1–0.3% annually under consistent application. This helps mitigate climate change while promoting long-term soil health.

Cow dung extract is gaining importance in sustainable agriculture due to its scientifically supported effects on soil health, plant growth, and environmental safety. It is commonly used in traditional formulations such as Jeevamrit and is a key input in Zero Budget Natural Farming systems practiced widely in India. Additionally, cow dung extract is non-toxic and aligns with principles of green chemistry. Unlike chemical fertilizers, it does not lead to soil acidification or groundwater contamination. Its use supports biodiversity by fostering a healthy ecosystem of soil organisms.

What is Dewatering of Cow Dung?

Dewatering of cow dung is a mechanical process that removes excess water from fresh dung, converting it into a semi-solid form. This is achieved through specialized machines designed to separate liquid from solid material efficiently. After dewatering, cow dung is divided into:

Solid fraction: Contains about 30–40% moisture

Liquid fraction: Contains dissolved nutrients and organic matter

The solid portion is easier to handle and ideal for composting or use as organic fertilizer, while the liquid portion can be reused for irrigation or further processed in biogas systems.

Working Principle of Dewatering Machines

Cow dung dewatering machines operate using advanced mechanical and physical principles of solid-liquid separation. The most common technologies include:

1. Screw Press Technology: This is the most widely used method. Cow dung is fed into a cylindrical chamber where a rotating screw compresses the material. The pressure forces water out through perforated screens, leaving behind semi-solid dung.

Scientific principles involved:

Mechanical compression
Pressure gradient formation
Filtration through mesh or screen

2. Centrifugal Separation: In some systems, centrifugal force is used to spin the dung at high speed. Due to density differences, heavier solid particles move outward, while lighter liquid remains closer to the center.

3. Belt Press System: This method uses two moving belts to squeeze the dung, removing water through pressure and filtration.

Product Comparison:

Attribute	Automatic Cow Dung De-watering Screw Press Machine	Semi Automatic 3HP Cow Dung Dewatering Machine	Automatic Cow Dung Dewatering Machine 10 HP	Screw Press Separator JX-YZ-500
Capacity	1–4 m^3/hr	~500 kg/hr	~4 ton/hr	Very high (industrial)
Automation	Automatic	Semi-auto	Fully automatic	Industrial
Power	~7.5 HP	~3 HP	~10 HP	High
Best for	Small farms	Small–medium farms	Large farms	Industrial plants
Price range	₹60K	₹1.5–2L	₹5–6L	₹8L+

How to Choose (Important)

1. **Under 20 cows** → small machine (₹50K–₹2L)
2. **20–100 cows** → mid-range (₹2L–₹5L)
3. **100+ cows / biogas plant** → heavy-duty (₹5L–₹10L+).

Benefits of Using Cow Dung Dewatering Machine

1. Reduces storage volume by **50–70%**
2. Makes **organic fertilizer easier to transport**
3. Improves **biogas production efficiency**

Separates liquid fertilizer (can be used directly in fields)

Scientific Composition of Cow Dung

Understanding the composition of cow dung helps explain the importance of dewatering. Fresh cow dung typically contains:

Water: 75–85%

Organic matter: 14–18%

Nitrogen (N): 0.5–1.5%

Phosphorus (P_2O_5): 0.2–0.5%

Potassium (K_2O): 0.5–1.0%

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Additionally, cow dung contains beneficial microorganisms such as methanogenic bacteria, which are vital for biogas production.



Importance of Dewatering Cow Dung Using Machines

1. Efficient Waste Management: Dewatering significantly reduces the volume of cow dung. Scientific studies show that lowering moisture content from 80% to 40% can reduce volume by nearly 50–60%. This makes storage, handling, and disposal much easier and more economical.

It also prevents accumulation of waste, reducing odor and minimizing breeding grounds for flies and pathogens.

2. Improved Organic Fertilizer Production: The solid fraction obtained after dewatering is rich in nutrients and has optimal moisture content for composting.

Scientific advantages:

Ideal moisture level (30–40%) supports aerobic decomposition
Improved carbon-to-nitrogen (C:N) ratio (around 20:1 to 25:1)
Faster decomposition and higher nutrient retention
This results in high-quality organic manure that enhances soil fertility and supports sustainable agriculture.

3. Enhanced Biogas Production: Biogas plants rely on anaerobic digestion, which requires an optimal solid concentration known as Total Solids (TS). Excess water in raw dung reduces digestion efficiency.

Dewatering helps maintain TS levels around 8–12%, which is ideal for microbial activity.

Scientific benefits:

a. Increased biogas yield by 10–25%
b. Methane concentration improves to 55–65%
c. Better performance of methanogenic bacteria
d. Thus, dewatering contributes directly to improved renewable energy production.

4. Reduction of Greenhouse Gas Emissions: Untreated cow dung releases gases such as: Methane (CH_4), Nitrous oxide (N_2O). Methane is especially harmful, having a global warming potential 28 times greater than CO_2 over 100 years. By dewatering and properly managing dung:

a. Methane emissions are significantly reduced
b. Organic carbon is stabilized
c. Environmental impact is minimized

5. Prevention of Water Pollution: Liquid runoff from raw cow dung contains high levels of pollutants:

a. Biochemical Oxygen Demand (BOD): 2000–5000 mg/L
b. Chemical Oxygen Demand (COD): 5000–10000 mg/L

If released untreated, it can contaminate water bodies, harming aquatic life. Dewatering allows separation of liquid waste, which can be treated or reused safely, reducing pollution risks.

6. Reduction in Transportation and Storage Costs: Wet cow dung is heavy and occupies more space, increasing transportation costs. After dewatering:

a. Weight decreases significantly
b. Bulk density reduces
c. Transportation costs drop by 30–50%
d. Additionally, semi-dry dung can be stored longer without odor or rapid decomposition.

7. Improved Farm Hygiene and Animal Health: High moisture dung promotes the growth of harmful microorganisms such as *E. coli* and *Salmonella*. Dewatering reduces moisture levels, limiting microbial growth and improving hygiene conditions in farms. This leads to:

a. Reduced disease risk
b. Better animal health
c. Cleaner working environment

8. Labor and Time Efficiency: Manual handling of wet cow dung is labor-intensive and time-consuming. Dewatering machines automate the process, saving time and reducing labor requirements. This is especially beneficial in large dairy farms where large quantities of dung are produced daily.

9. Resource Recovery and Circular Economy: Dewatering supports the concept of a circular economy, where waste is converted into valuable resources.

Solid fraction → Organic fertilizer or compost

Liquid fraction → Nutrient-rich irrigation water or biogas feed

This ensures efficient utilization of resources and reduces waste generation.

Applications for Cow Dung Dewatering Machines

These machines are widely used in:

1. Dairy farms
2. Biogas plants
3. Organic farming systems
4. Vermicomposting units
5. Agro-industrial waste management facilities

They are particularly important in regions with intensive livestock farming where efficient waste management is essential.

Conclusion

Dewatering cow dung using machines is a scientifically proven and highly effective method for managing livestock waste. By reducing moisture content, it improves waste handling, enhances fertilizer quality, increases biogas production, and minimizes environmental pollution. Scientific data clearly shows that dewatering contributes to reduced greenhouse gas emissions, prevention of water contamination, and improved resource utilization. It also reduces operational costs and improves farm hygiene and productivity. In modern agriculture, where sustainability, efficiency, and environmental protection are key priorities, cow dung dewatering machines play a vital role. They transform cow dung from a problematic waste into a valuable resource, supporting both economic development and ecological balance.

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Green Invaders: A Silent Battle in Our Ecosystems

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Vennila S[1]., Suganthi S[2]

[1]Assistant Professor (Forestry), Agricultural College and Research Institute, TNAU, Vazhavachanur, Tiruvannamalai.

[2]Assistant Professor (PBG), Agricultural College and Research Institute, TNAU, Vazhavachanur, Tiruvannamalai.

Introduction

Nature is often perceived as a balanced and self-regulating system, where diverse species coexist in harmony. However, this balance is increasingly being disrupted by the spread of invasive plant species—often referred to as "green invaders." These non-native species, introduced intentionally or accidentally, establish, spread rapidly and outcompete native vegetation, thereby altering ecosystem structure and function. Unlike natural ecological changes, the invasion of these species is largely driven by human activities such as global trade, transportation and land-use changes.

Across India and many parts of the world, invasive plants like Lantana camara, *Parthenium hysterophorus*, *Eichhornia crassipes*, and *Prosopis juliflora* have become dominant in forests, agricultural lands, and water bodies. Their aggressive growth, high reproductive capacity, and lack of natural enemies enable them to spread unchecked, displacing native species and reducing biodiversity. This silent invasion often goes unnoticed until significant ecological and economic damage has already occurred.

The growing presence of green invaders represents a hidden yet serious environmental challenge. Their impact extends beyond ecological degradation to affect agriculture, water resources, and rural livelihoods. Understanding the nature, spread, and consequences of invasive species is therefore essential to develop effective management strategies and restore ecological balance. This article explores the dynamics of invasive plants and highlights the urgent need to address this silent battle unfolding within our ecosystems.

Status of Invasive Species

India, recognized for its rich biodiversity, is facing a significant threat from invasive alien species (IAS) that are rapidly spreading across various ecosystems, including forests, wetlands, agricultural lands, and coastal areas. The invasion crisis is alarming, with invasive plants expanding over approximately 15,500 square kilometers annually. Over 190 IAS have been identified, which include a diverse range of plants, animals, insects, and aquatic organisms that disrupt native biodiversity and ecosystem functions. Noteworthy invasive species such as *Lantana camara*, *Parthenium hysterophorus*, *Eichhornia crassipes*, and *Prosopis juliflora* have caused considerable ecological and economic harm.

In Tamil Nadu, the state has taken a proactive stance against invasive species through policy initiatives and field interventions. The introduction of the Tamil Nadu Policy on Invasive Plants and Ecological Restoration (TN PIPER) in 2021 marks a significant step in managing IAS at the state level. Despite these efforts, the extent of invasion remains substantial, with major invasive species like *Prosopis juliflora*, *Lantana camara*, *Senna spectabilis* and *Acacia mearnsii* affecting approximately 177,000 hectares of forest. Management efforts have cleared about 36,700 hectares by 2025, but field assessments indicate that over 100 invasive plant species are present in Sathyamangalam Tiger Reserve and around 48 species in Srivilliputhur Wildlife Sanctuary. The Western Ghats, particularly regions like Nilgiris, Anaikatty, and Mudumalai National Park, are severely impacted by dense invasions, notably by *Senna spectabilis*, which threatens native biodiversity.

The distribution of major invasive species in India reveals extensive geographical spread and ecological challenges. *Lantana camara* is particularly widespread, covering an estimated 13–15 million hectares, primarily in forest understoreys and degraded lands. *Parthenium hysterophorus* has invaded around 5–6 million hectares, affecting agricultural lands and urban areas. The aquatic invasive species Eichhornia crassipes infests over 2 million hectares of water bodies, compromising water quality and aquatic biodiversity. *Prosopis juliflora* dominates arid regions, spreading across 5–7 million hectares, especially in Tamil Nadu, Gujarat, and Rajasthan. The collective expansion of these species underscores the urgent need for effective management and restoration strategies to mitigate their impact on ecosystems.

How do they Spread?

Invasive species in India proliferate through both natural processes and human activities, enabling them to quickly occupy new habitats and outcompete indigenous flora. A significant method of spread is intentional introduction, where species are brought in for purposes such as ornamental gardening, forestry, agriculture, or erosion control. For examples plants like *Lantana camara* and *Prosopis juliflora*, which were initially introduced for aesthetic and land rehabilitation reasons but have since become uncontrollable.

Accidental introductions also play a crucial role, particularly through trade and transportation. Invasive species like *Parthenium hysterophorus* often infiltrate new areas via contaminated crop seeds, machinery, vehicles and the movement of goods. Aquatic invasives, such as *Eichhornia crassipes*, spread through waterways, irrigation channels and flooding events.

Natural mechanisms contribute significantly to the spread of invasive species. Many invasive plants produce a high volume of seeds that are easily dispersed by wind, water and animals. Birds and livestock can transport seeds over considerable distances, while rivers and monsoon floods facilitate rapid regional spread. Additionally, environmental disturbances, including deforestation, overgrazing and land degradation, create favorable conditions for invasive species to establish dominance.

Overall, the spread of invasive species in India is a multifaceted issue driven by human-mediated movement, environmental changes and the inherent biological advantages of these species, presenting a complex and ongoing challenge for management and control efforts.

Impacts on Ecosystems

The effects of green invaders on ecosystems are significant and far-reaching, influencing both ecological balance and the functioning of natural systems. One of the most notable impacts is the loss of biodiversity, as invasive species outcompete and replace native plants, leading to reduced species diversity and degraded wildlife habitats; for instance, aggressive invaders like *Lantana camara* form dense thickets that suppress native vegetation and limit food and shelter for animals. Invasive plants also adversely affect soil health through mechanisms such as allelopathy, where they release chemicals that inhibit the germination and growth of nearby plants, further restricting native flora. Another major consequence is the depletion of water resources, as many invasive species consume large amounts of water, reducing availability for native plants, agriculture, and groundwater recharge; this is particularly evident in *Prosopis juliflora*, which thrives in arid regions and extracts substantial soil moisture. Moreover, invasive plants can increase fire risks by accumulating high levels of dry biomass that act as fuel, intensifying the frequency and severity of forest fires, with species like Lantana playing a notable role. Over time, these combined effects can drastically transform ecosystems by altering their structure, nutrient cycles, and hydrological processes, ultimately reducing their resilience to environmental stresses such as climate change, drought, and human disturbances and threatening long-term ecological sustainability and biodiversity conservation.

Economic and Social Consequences

The impact of invasive species extends far beyond ecological damage, creating serious economic burdens and social challenges, particularly in a country like India where livelihoods are closely linked to natural resources. In agriculture, invasive weeds such as *Parthenium hysterophorus* and *Lantana camara* compete aggressively with crops for nutrients, water, and sunlight, leading to significant reductions in crop yields and increased cost of cultivation due to the need for additional weeding, herbicides and labor. In grazing systems, these species reduce the availability and quality of fodder, directly affecting livestock productivity and farmers' income.

For forest-dependent communities, invasive species pose a major threat by limiting access to essential resources such as fodder, fuelwood, non-timber forest products (NTFPs), and medicinal plants. Dense invasions by species like *Prosopis juliflora* often make forest areas inaccessible, thereby affecting traditional livelihoods and increasing the time and effort required for resource collection, especially for rural women.

In aquatic ecosystems, invasives such as *Eichhornia crassipes* clog waterways, irrigation canals and reservoirs, disrupting irrigation, fisheries, and transport. This leads to economic losses in fisheries, reduced water availability for agriculture and increased maintenance costs for clearing water bodies.

The financial burden on governments and conservation agencies is also substantial. Large-scale efforts for removal, monitoring, and ecological restoration require continuous investment in manpower, machinery, and research. Despite these efforts, complete eradication is rarely achieved, making management a recurring expense. Additionally, invasive species can indirectly impact public health for example, Parthenium causes allergies, skin irritation, and respiratory issues leading to increased healthcare costs and reduced workforce productivity.

Overall, invasive species undermine rural livelihoods, food security and economic stability, disproportionately affecting vulnerable communities. Addressing these challenges requires not only ecological management but also integrated socio-economic strategies involving policy support, community participation and sustainable restoration practices.

Managing the Threat

Controlling green invaders is a complex and ongoing challenge, but a combination of well-planned strategies can significantly reduce their spread and impact. Early detection and rapid response play a critical role in preventing invasive species from becoming established, as timely identification allows for quicker and more effective control measures. Once established, mechanical removal methods such as uprooting, cutting, and in some cases controlled burning are commonly used to reduce invasive plant populations. However, these methods often require continuous effort and

monitoring. Another sustainable approach is biological control, which involves the use of natural enemies such as insects, pathogens, or grazing organisms to suppress invasive species like *Parthenium hysterophorus* and *Lantana camara*. Equally important is public awareness and community participation, as local communities, farmers and stakeholders play a key role in identifying, reporting and managing invasions. Furthermore, restoration of native vegetation after removal is essential to prevent reinvasion, as healthy ecosystems with strong native plant communities are more resistant to invasive species.

The battle against green invaders extends beyond forests and protected areas; it is a shared responsibility involving farmers, policymakers, scientists, and the general public. Sustainable management requires coordinated efforts, informed policies, and active participation from all sectors of society. Simple yet impactful actions such as avoiding the introduction and planting of exotic species, promoting native plants and supporting biodiversity conservation initiatives can collectively make a significant difference in controlling the spread of invasive species.

Conclusion

The spread of invasive species represents a silent but powerful force that is reshaping ecosystems across the world. Although their impacts often occur gradually and may go unnoticed initially, the long-term consequences are profound, affecting biodiversity, ecosystem services and human livelihoods. Protecting our natural environment from these green invaders requires increased awareness, timely intervention and a strong commitment to preserving ecological balance. Only through sustained and collective action can we safeguard the resilience and sustainability of our ecosystems for future generations.

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Integrated Disease Management (IDM) Strategies for Sustainable Agriculture

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Hari Sankar Sai Muragadapu[1], Yaswanthika Sai Pakki[2]
[1]M.Sc. Agriculture, Department of Vegetable Science, College of Agriculture, Bhubaneswar, Odisha University of Agriculture and Technology, Odisha.
[2]B.Sc. (Hons.) Agriculture, Chaudhary Charan Singh University, Meerut, Uttar Pradesh.

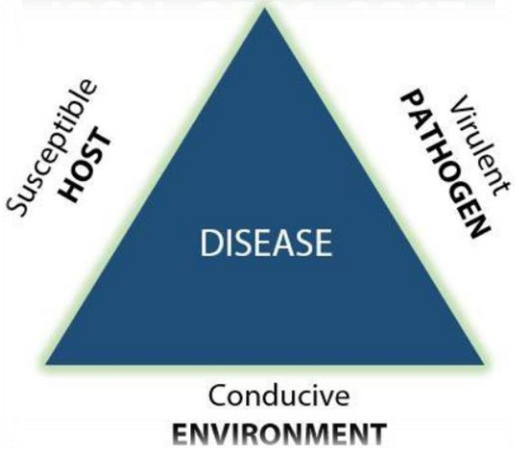
Abstract
Integrated Disease Management (IDM) represents a holistic, environmentally sound, and economically viable strategy for managing plant diseases in modern agriculture. It integrates diverse approaches including cultural, biological, genetic, physical, and chemical methods to maintain disease incidence below economic threshold levels while minimizing ecological disruption. With the increasing challenges of pesticide resistance, environmental degradation, and climate variability, IDM has emerged as a cornerstone of sustainable agriculture. This review provides an extensive and in-depth analysis of IDM principles, components, strategies, emerging technologies, challenges, and future prospects. The role of IDM in enhancing crop productivity, ecological balance, and long-term agricultural sustainability is critically examined.

Introduction
Plant diseases constitute a major limiting factor in agricultural productivity worldwide, leading to substantial economic losses and threatening global food security. The intensification of agriculture, monoculture practices, and indiscriminate use of agrochemicals have contributed to the emergence and spread of plant pathogens. Over-reliance on chemical pesticides has further aggravated issues such as environmental contamination, development of resistant pathogen strains, and adverse impacts on non-target organisms.

In this context, Integrated Disease Management (IDM) has emerged as a scientifically robust and ecologically sustainable approach that emphasizes the integration of multiple disease control strategies. IDM is not merely a set of practices but a dynamic decision-making process that combines knowledge of plant pathology, agroecology, and crop management. It aims to maintain disease levels below economically damaging thresholds while ensuring environmental safety and long-term sustainability (Ciancio et al., 2007).

Concept and Principles of IDM
Integrated Disease Management can be defined as the coordinated and judicious use of multiple compatible disease management strategies based on ecological principles and economic considerations to suppress plant diseases effectively (Khokhar et al., 2014). The fundamental concept of IDM revolves around disrupting the interaction between the host, pathogen, and environment, commonly referred to as the disease triangle.

The principles of IDM are deeply rooted in classical plant disease management concepts such as avoidance, exclusion, eradication, protection, and host resistance. Avoidance involves altering agronomic practices such as planting time and crop selection to escape disease-prone conditions. Exclusion focuses on preventing the introduction of pathogens through quarantine and sanitation measures. Eradication aims to eliminate existing inoculum sources through crop rotation, removal of infected residues, and soil treatments. Protection involves safeguarding plants using chemical or biological agents, while host resistance emphasizes the use of resistant or tolerant cultivars. These principles function collectively rather than independently, ensuring a comprehensive and resilient disease management strategy.



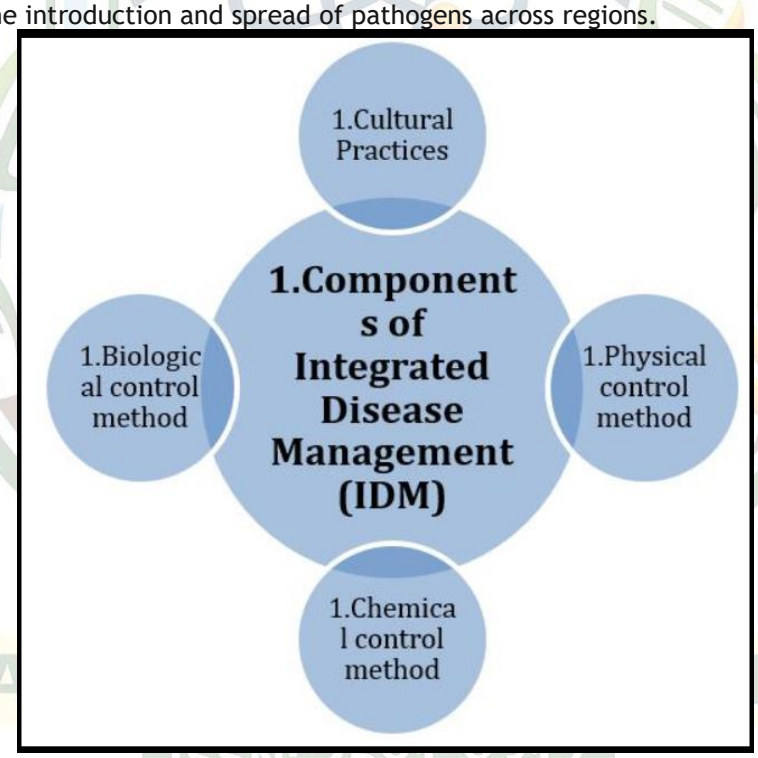
The effectiveness of IDM lies in the integration of multiple complementary components that collectively reduce disease incidence and severity. Cultural practices form the foundation of IDM as they modify the agroecosystem to make it less conducive to pathogen development. Practices such as crop rotation disrupt pathogen life cycles, while intercropping enhances biodiversity and reduces disease spread. Field sanitation eliminates sources of inoculum, and proper irrigation management prevents conditions favorable for pathogen proliferation. Soil health management through organic amendments enhances microbial diversity, which in turn suppresses soil-borne pathogens.

Host plant resistance represents one of the most reliable and cost-effective approaches within IDM. The use of resistant cultivars significantly reduces disease incidence without additional input costs. Advances in plant breeding, molecular genetics, and genome editing technologies have accelerated the development of resistant varieties with improved durability and broad-spectrum resistance.

Biological control has gained considerable importance as an eco-friendly alternative to chemical control. Beneficial microorganisms such as Trichoderma, Pseudomonas, and Bacillus species suppress plant pathogens through mechanisms including antibiosis, competition, parasitism, and induction of systemic resistance. The integration of biological control agents into IDM not only reduces reliance on chemical pesticides but also enhances soil health and ecological balance.

Chemical control, although essential in certain situations, is used judiciously within IDM frameworks. The emphasis is on need-based application of selective and low-toxicity fungicides, guided by disease monitoring and economic thresholds. This approach minimizes the risk of resistance development and environmental contamination.

Physical and mechanical methods also contribute to IDM by reducing pathogen load through non-chemical means. Techniques such as soil solarization and hot water seed treatment are effective in managing soil-borne and seed-borne pathogens. Regulatory measures, including plant quarantine and certification of disease-free planting material, play a crucial role in preventing the introduction and spread of pathogens across regions.



IDM Strategies for Sustainable Agriculture

IDM strategies are broadly categorized into preventive and curative approaches, although in practice they are applied in an integrated manner. Preventive strategies focus on reducing the risk of disease occurrence by employing healthy planting materials, adopting crop rotation, and improving soil health. These measures create an unfavourable environment for pathogen establishment and proliferation.

Curative strategies are implemented after the onset of disease and involve targeted interventions such as fungicide application, removal of infected plant parts, and application of biological agents. The success of curative measures depends on timely detection and accurate diagnosis of diseases.

The integration of multiple strategies enhances the overall effectiveness of IDM. For instance, the combination of resistant varieties, crop rotation, and biological control agents has been shown to significantly reduce disease severity and improve crop yields. Similarly, the integration of disease forecasting models with timely chemical applications optimizes resource use and minimizes environmental impact (Raman et al., 2026).



Role of IDM in Sustainable Agriculture

Integrated Disease Management plays a pivotal role in promoting sustainable agriculture by addressing environmental, economic, and social dimensions. From an environmental perspective, IDM reduces the dependence on chemical pesticides, thereby minimizing pollution and preserving biodiversity. It also enhances soil health through the promotion of beneficial microbial communities.

Economically, IDM contributes to reduced input costs and improved yield stability, making it a viable option for small and marginal farmers. By preventing severe disease outbreaks, IDM ensures consistent productivity and reduces financial risks. Socially, IDM promotes food safety by reducing pesticide residues in agricultural produce. It also safeguards farmer health by minimizing exposure to hazardous chemicals and encourages the adoption of environmentally responsible farming practices.

Technological Advancements in IDM

Recent technological advancements have significantly enhanced the effectiveness of IDM strategies. Precision agriculture tools such as remote sensing and geographic information systems enable early detection and monitoring of plant diseases. These technologies facilitate site-specific management and optimize resource utilization. Disease forecasting models based on weather parameters provide valuable insights into disease dynamics and help in predicting outbreaks. Such models enable farmers to implement timely control measures, thereby reducing unnecessary pesticide applications.

Biotechnological approaches, including marker-assisted selection and genome editing, have revolutionized the development of disease-resistant crops. RNA interference and other molecular techniques offer innovative solutions for targeted pathogen control. Nanotechnology has also emerged as a promising field in IDM, with the development of nano-fungicides that offer controlled release and enhanced efficacy. These advancements contribute to reducing environmental impact while maintaining effective disease control.

Challenges in IDM Implementation

Despite its numerous advantages, the adoption of IDM faces several challenges. Limited awareness and lack of technical knowledge among farmers hinder the widespread implementation of IDM practices. Economic constraints, particularly in developing countries, restrict access to quality inputs such as biocontrol agents and resistant varieties. Climate change poses a significant challenge by altering pathogen behaviour and disease epidemiology, leading to the emergence of new diseases and increased severity of existing ones. Institutional and policy-related issues, including inadequate extension services and weak regulatory frameworks, further limit the adoption of IDM.

Future Prospects and Opportunities

The future of IDM lies in the integration of advanced technologies with traditional knowledge systems. The development of climate-resilient disease management strategies will be crucial in addressing the challenges posed by global climate change. The incorporation of artificial intelligence and machine learning into disease diagnosis and management holds immense potential for improving decision-making processes. Strengthening farmer participation through extension programs and capacity-building initiatives will be essential for the successful implementation of IDM. Policy support in the form of subsidies for eco-friendly inputs and promotion of sustainable practices will further accelerate the adoption of IDM.

Case Studies

The successful implementation of IDM can be observed in several cropping systems. In rice cultivation, the integration of resistant varieties, proper spacing, and need-based fungicide application has effectively controlled blast disease. In potato, the use of forecasting models combined with timely fungicide sprays has significantly reduced the incidence of late blight. In banana cultivation, the integration of crop rotation, organic amendments, and biological control has proven effective in managing Fusarium wilt.

Conclusion

Integrated Disease Management represents a comprehensive and sustainable approach to plant disease control, combining ecological principles with modern technological advancements. By integrating multiple compatible strategies, IDM reduces reliance on chemical pesticides, enhances agroecosystem resilience, and ensures long-term agricultural sustainability. The successful adoption of IDM requires coordinated efforts among researchers, policymakers, and farmers, along with continuous innovation and knowledge dissemination. As agriculture faces increasing challenges from climate change and resource limitations, IDM will play a critical role in ensuring global food security and environmental sustainability.

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Biological Control of Plant Diseases Opportunities and Challenges

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Dr. Ashok Kumar Koshariya[1], Dr. Shayam Singh[2], Dr. Sandhaya Baghel[3]
[1]Scientist (Plant Pathology), GGD, RARS, IGKV, Kawardha, Chhattisgarh.
[2]Associate Professor (Plant Pathology), SKCARS, IGKV, Kawardha, Chhattisgarh.
[3]Assistant Professor (Chemistry), JLN Art and Science PG College, Bemetara, Chhattisgarh.

Abstract

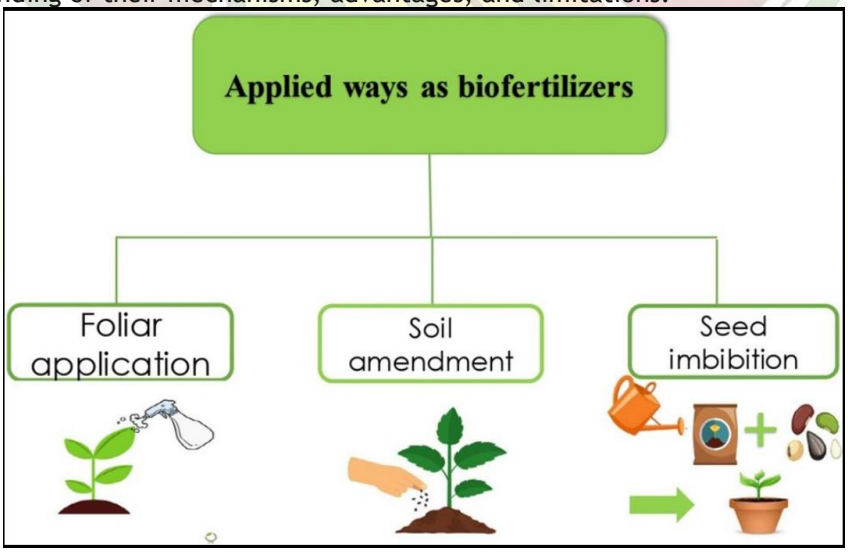
Biological control of plant diseases has emerged as a sustainable and environmentally sound alternative to chemical-based disease management strategies. It involves the utilization of beneficial microorganisms to suppress plant pathogens through diverse ecological interactions. With increasing concerns over pesticide resistance, environmental degradation, and food safety, biological control has gained significant attention in modern agriculture. This review provides an in-depth analysis of biological control agents, their mechanisms, applications, opportunities, and limitations. It further highlights recent advancements in biotechnology and microbial ecology that are shaping the future of biological disease management. Despite its promise, biological control faces challenges related to consistency, formulation, and commercialization. Strategic integration with advanced technologies and agricultural practices is essential for its successful implementation.

Introduction

Plant diseases are a major constraint to agricultural productivity worldwide, causing significant economic losses and threatening food security. Fungal, bacterial, and viral pathogens adversely affect crop growth, yield, and quality. Traditionally, chemical pesticides have been the primary means of disease control. However, their indiscriminate use has led to several problems, including environmental pollution, development of resistant pathogen strains, and adverse effects on non-target organisms.

Biological control, defined as the use of living organisms to suppress plant pathogens, offers a sustainable alternative. It relies on ecological interactions between beneficial microorganisms and plant pathogens, promoting a natural balance within the agroecosystem. Biological control agents (BCAs) such as *Trichoderma*, *Bacillus*, *Pseudomonas*, and *Streptomyces* are widely studied for their ability to control plant diseases while enhancing plant growth and soil health (Yao et al., 2023; Ayaz et al., 2023).

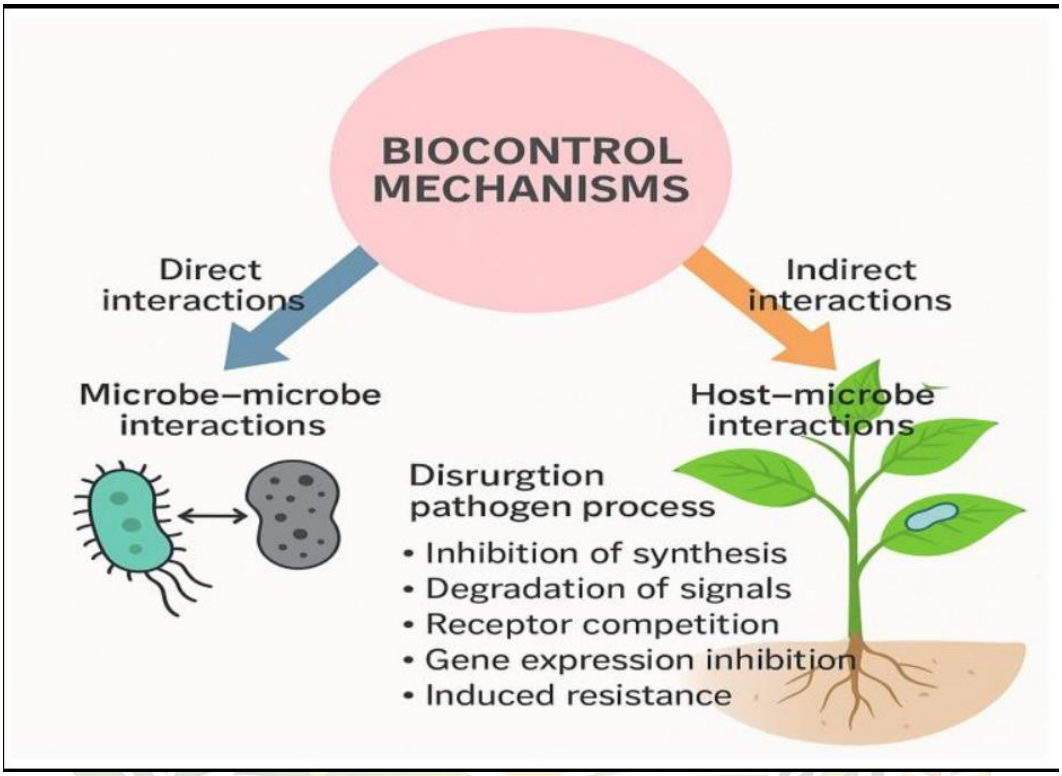
The increasing emphasis on sustainable agriculture and integrated pest management (IPM) has further accelerated the adoption of biological control strategies. However, the practical implementation of these methods requires a comprehensive understanding of their mechanisms, advantages, and limitations.



Concept and Principles of Biological Control

Biological control is fundamentally based on ecological principles governing interactions among plants, pathogens, and beneficial microorganisms. Unlike chemical control, which aims at pathogen eradication, biological control focuses on suppressing pathogen populations to manageable levels.

The key principles include ecological balance, competition for resources, and enhancement of host resistance. Beneficial microorganisms colonize plant surfaces and the rhizosphere, forming a protective barrier against pathogens. These interactions are dynamic and influenced by environmental conditions such as soil type, temperature, moisture, and microbial diversity. Biological control operates through both direct antagonism and indirect stimulation of plant defense mechanisms. The success of BCAs depends on their ability to establish, survive, and compete effectively in the target environment.



Types of Biological Control

Biological control strategies can be broadly classified into three categories based on their mode of application and ecological approach.

1. Classical Biological Control: This approach involves the introduction of natural enemies into a new environment to control invasive pathogens. Although more common in insect pest management, it has limited application in plant disease control.

2. Augmentative Biological Control: Augmentative control involves the mass production and application of BCAs in agricultural systems. It includes both inoculative and inundative releases, where microorganisms are applied to seeds, soil, or plant surfaces to suppress pathogens.

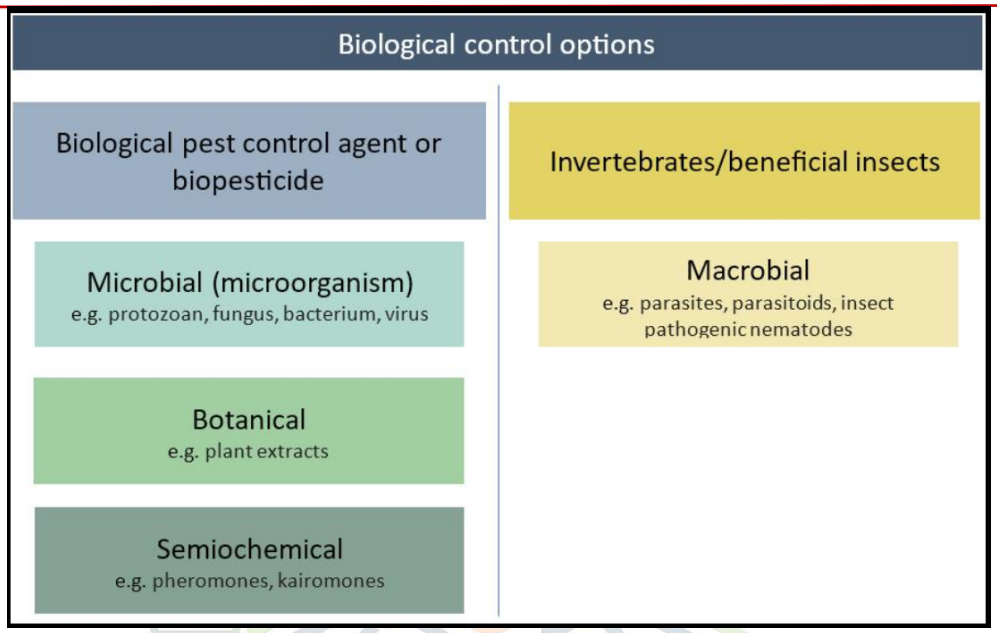
3. Conservation Biological Control: This strategy focuses on enhancing native beneficial microbial populations through agronomic practices such as organic amendments, crop rotation, and reduced pesticide use. Conservation biological control promotes a stable and resilient agroecosystem.

Major Biological Control Agents

1. Fungal Agents: Fungal BCAs, particularly *Trichoderma spp.*, are among the most widely used agents in biological control. They are highly effective against soil-borne pathogens such as *Fusarium*, *Rhizoctonia*, and *Sclerotium*. *Trichoderma* species exhibit rapid growth, efficient colonization, and strong antagonistic properties, making them ideal candidates for bioformulations (Yao et al., 2023). Other fungal agents include *Gliocladium*, *Penicillium*, and *Chaetomium*, which contribute to pathogen suppression through enzyme production and competition.

2. Bacterial Agents: Bacterial BCAs such as *Bacillus subtilis*, *Pseudomonas fluorescens*, and *Bacillus amyloliquefaciens* play a crucial role in disease suppression. These bacteria produce a wide range of antimicrobial compounds, including antibiotics, lipopeptides, and siderophores that inhibit pathogen growth (Ayaz et al., 2023). Their ability to form endospores enhances their survival under adverse environmental conditions, making them suitable for commercial applications.

3. Actinomycetes: Actinomycetes, particularly *Streptomyces spp.*, are known for their ability to produce diverse secondary metabolites with antimicrobial properties. They contribute significantly to soil health and disease suppression.



Mechanisms of Biological Control

Biological control agents employ multiple mechanisms to suppress plant pathogens, which can be categorized into direct and indirect modes of action.

1. Competition for Nutrients and Space: BCAs compete with pathogens for essential nutrients such as carbon, nitrogen, and iron. Siderophore production by bacteria limits iron availability to pathogens, thereby inhibiting their growth.

2. Antibiosis: Antibiosis involves the production of antimicrobial compounds that directly inhibit or kill pathogens. These include antibiotics, volatile organic compounds, and toxins (Tariq et al., 2020).

3. Mycoparasitism: Certain fungal BCAs directly parasitize pathogenic fungi by penetrating their hyphae and degrading their cell walls using enzymes such as chitinases and glucanases (Asad et al., 2022).

4. Induced Systemic Resistance (ISR): BCAs can activate plant defence pathways, leading to enhanced resistance against a wide range of pathogens. ISR involves signalling pathways mediated by jasmonic acid and ethylene.

5. Plant Growth Promotion: Many BCAs promote plant growth by enhancing nutrient uptake, producing phytohormones, and improving root architecture. This indirectly reduces disease susceptibility.

Applications in Plant Disease Management

Biological control has been successfully applied in various agricultural systems for managing plant diseases. It is particularly effective in controlling soil-borne pathogens responsible for diseases such as damping-off, root rot, and wilt.

Seed treatment with BCAs improves germination and seedling vigour, while soil application enhances rhizosphere colonization. Foliar application of BCAs is also effective against leaf pathogens. Post-harvest diseases are increasingly being managed using biological agents to reduce losses during storage and transportation. The integration of biological control into IPM programs has demonstrated significant potential in reducing chemical pesticide use while maintaining crop productivity.

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Opportunities in Biological Control

Biological control offers numerous opportunities for sustainable agriculture. It reduces environmental pollution and minimizes risks to human health. The compatibility of BCAs with organic farming practices makes them an essential component of eco-friendly agriculture.

Advances in molecular biology and microbial ecology have opened new avenues for improving the efficacy of BCAs. The study of plant microbiomes has revealed complex interactions that can be harnessed for disease suppression. The development of microbial consortia and synthetic communities represents a promising approach to enhance stability and effectiveness. Furthermore, climate-resilient agriculture can benefit from biological control strategies that improve ecosystem resilience.

Challenges and Constraints

Despite its advantages, biological control faces several challenges that limit its widespread adoption. One of the major limitations is the inconsistency in field performance due to environmental variability. Factors such as soil conditions,

temperature, and moisture influence the survival and activity of BCAs. Formulation and shelf-life issues pose significant challenges for commercialization. Maintaining microbial viability during storage and transportation is critical.

Biological control agents often exhibit slower action compared to chemical pesticides, which may discourage farmers seeking immediate results. Additionally, the specificity of some BCAs limits their applicability across different crops and pathogens. Regulatory hurdles, lack of awareness, and limited availability of high-quality bioformulations further hinder adoption. Interaction with native microbial communities may also affect the efficacy of introduced BCAs.

Integration with Advanced Technologies

Recent advancements in biotechnology are transforming biological control strategies. Genomics and transcriptomics are being used to identify genes involved in antagonism and plant-microbe interactions. CRISPR-based genome editing offers opportunities to enhance the efficacy of BCAs. Nanotechnology is being explored for developing advanced formulations with improved stability and delivery. Artificial intelligence and precision agriculture tools can optimize the application of BCAs based on environmental conditions and disease forecasts.

Future Perspectives

The future of biological control lies in the development of robust, multi-functional microbial consortia that can provide consistent performance under diverse conditions. Integration with sustainable agricultural practices and advanced technologies will be crucial. Policy support, farmer education, and investment in research and development are essential to promote large-scale adoption. Strengthening regulatory frameworks and quality control measures will ensure the availability of effective bio-products.

Conclusion

Biological control represents a viable and sustainable alternative to chemical disease management. Its eco-friendly nature, multifaceted mechanisms, and compatibility with modern agricultural practices make it a key component of sustainable crop production systems. However, addressing the challenges related to efficacy, formulation, and commercialization is essential for its widespread adoption. Continued research and technological innovations will play a critical role in unlocking the full potential of biological control in agriculture.

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Advancements in Emerging Food Processing Technologies Enhancing Sustainability and Functionality of Plant-Based Foods

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Peetha Dharani[1], Pratibha Singh[2]

[1] Research Scholar, [2]Associate Professor,

Department of Food Plant Operations, Incubation and Entrepreneurship, NIFTEM T National Institute of Food Technology Entrepreneurship and Management Thanjavur, (NIFTEM T).

Abstract

The growing demand for healthy and sustainable food has spurred the development of plant-based products as substitutes for animal proteins. However, these plant proteins often have limitations in texture, functionality, and sensory characteristics. Emerging technologies in food processing, such as high-pressure processing, pulsed electric fields, ultrasound, and cold plasma, show great potential for food formulation. Non-thermal food processing improves the functional properties of proteins and provides better and more sustainable solutions in terms of energy and environmental impact for the extraction of plant-based proteins. Moreover, the extraction and functional properties of plant-based proteins can be combined with improved antioxidant activity, texture, and shelf-life due to the interactions between polyphenols and plant proteins. The combination of these processing technologies with digital monitoring and artificial intelligence promotes sustainable and efficient food production. The innovations of polyphenols and proteins, in addition to the processing technologies, can improve the quality and safety of plant-based proteins and increase consumer acceptance of future food systems.

Introduction

Food systems worldwide are changing rapidly. A growing global population puts pressure on the supply chain to produce sufficient food and protect Earth's resources. Traditional forms of food production, especially the meat industry, consume large amounts of land, water, and energy resources. They also significantly contribute to greenhouse gas emissions. Environmental and sustainability concerns have driven both researchers and consumers to explore meat alternatives, especially plant-based foods (Khouryieh, 2021; Rashwan et al., 2025). Plant-based foods are made mostly from plants, such as legumes, grains, pulses, oilseeds, and vegetables. Examples include plant-based meat, dairy alternatives, and protein-rich snacks. These foods are often enriched with extra fiber, vitamins, minerals, and beneficial phytochemicals. The production of plant-based foods uses considerably less natural resources and has a lower environmental impact than meat (Abreu et al., 2023).

Despite the benefits of plant-based foods, there are some drawbacks. Proteins from plants do not behave the same way upon processing as proteins from animal sources. As a result, they do not solubilize, gel, or even set as easily or at all. Additionally, some plant proteins have a negative taste, which is often described as beany or earthy, and even further limits their use. These factors compromise the sensory aspects of plant-based foods. To sidestep these challenges, researchers have been working on new food processing techniques that optimize the functionality of plant food components and improve the quality of the end products. Most of these techniques are less severe than conventional food processing methods, preserve nutrients in food, and improve food quality. Innovations such as bio-stress technologies, including high-pressure processing, pulsed electric fields, acoustics, and cold plasma processing, are included. These new approaches to food processing not only improve the quality of food but are also environmentally friendly as they consume less energy, produce less waste, and utilize resources more efficiently (Jiang et al., 2025; Yunusa & Dandago, 2025, 2025)

Emerging Food Processing Technologies

The development of non-thermal processes to enhance food quality, safety, and sustainability is an area of active interest. Instead of using conventional techniques, which involve cooking and modifying structures, non-thermal techniques use physical means such as pressure, electric fields, and sound to process food. An overview of the major emerging non-thermal food processing technologies is shown in *Table 1*. High-pressure processing (HPP) is a technique that modifies food using pressures of 100-600 MPa. Microorganisms are inactivated, and the food is not significantly heated (Pizarro-Oteiza et al., 2025). Short, high voltage pulses, called pulsed electric fields (PEF), create pores in cell membranes which lead to more efficient extraction of bioactive compounds from plant tissues (Caballero-Figueroa et al., 2022). Improved mass transfer facilitates extraction and is the result of cell structure disruption by cavitation bubbles during ultrasound processing (Wei et al., 2025). Reactive species produced from ionized gases are called cold plasma technology. Without heat treatment, reactive species can inactivate microorganisms on food surfaces (Li et al., 2025). The use of these techniques reduces energy consumption during food processing and improves food quality (Jiang et al., 2025).

Table.1: Emerging Processing Technologies to improve functionality and quality of plant-based food products:

Technology	Mechanism	Key Processing Parameters	Application	Reference
High-Pressure Processing (HPP)	High-pressure treatment	100–600 MPa pressure	Texture improvement and functionality improvement	(Pizarro-Oteiza et al., 2025)
Pulsed Electric Field (PEF)	High voltage electric pulses	10–80 kV/cm electric field	Enhanced extraction of plant compounds	(Caballero-Figueroa et al., 2022)
Ultrasound Processing	Acoustic cavitation	20–100 kHz frequency	Improved extraction and protein functionality	(Wei et al., 2025)
Cold Plasma Technology	Ionized gas treatment	High voltage plasma discharge	Microbial inactivation and shelf-life improvement	(Li et al., 2025)

Functional and Structural Modifications of Plant Proteins

Plant-based foods that replicate meat or dairy products rely on various plant proteins. However, plant proteins are generally inferior to animal proteins in terms of emulsification, foaming, and gelling. Positive sensory attributes are needed, so these traits must be improved. Emerging food processing technologies modify protein molecular structures, which improves their functional properties. Processing causes proteins to fold into different shapes. Structural changes affect food flow and the interaction of molecules with water, fat, and other components. Improved protein properties can enhance the bite and texture of plant-based meat products (Pizarro-Oteíza et al 2025). High-pressure processing can increase the water-holding capacity, gelling, and texture. Ultrasound processing breaks down large protein aggregates into smaller particles. A large surface area improves solubility and allows proteins to form stable emulsions and food structures (Wei et al. 2025). Pulsed electric fields disrupt cell structures, thereby improving protein extraction from plants. This leads to better functionality and higher yields of plant proteins (Caballero-Figueroa et al., 2022). Cold plasma processing has gained popularity. Reactive oxygen and nitrogen species alter protein structures, improving water retention, foam formation, and digestibility (Fernandes & Rodrigues, 2025). These new techniques make plant proteins more useful in food formulations and improve the quality of plant-based products.

Plant Protein-Polyphenol Interactions in Emerging Processing

Plant polyphenols include many bioactive compounds like tannins, phenolic acids, and flavonoids. These compounds have strong antioxidant properties and, during food processing, can bind with plant proteins, affecting the texture, color, and nutritional value of plant-based foods (Zhang et al., 2024). The mechanisms and functional outcomes of protein-polyphenol interactions in plant-based food systems are illustrated in *Fig* 2.

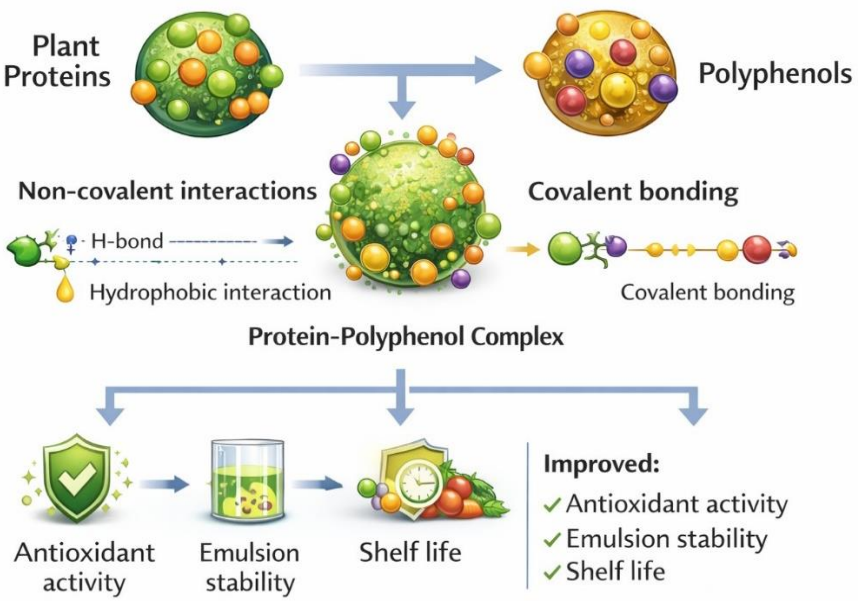


Fig 2. Schematic representation of mechanisms and functional outcomes of protein-polyphenol interactions in plant-based foods

Protein–polyphenol associations can result from hydrogen and other types of non-covalent interactions, and can also form covalent bonds. Some newer food processing technologies have a significant impact on these associations. For example, ultrasound processing has been shown to increase the activity and stability of emulsions and the antioxidant activity of food products by making additional binding sites available on proteins (Xue et al., 2024). Similarly, high-

pressure processing has been shown to promote the formation of protein–polyphenol complexes and increase the strength and water retention of protein gels due to its ability to alter the structural framework of proteins (Can Karaca et al., 2025). These associations, due to their antioxidant and antimicrobial properties, can improve the shelf life of food products. Enhancing the associations described can also result in considerable improvements in the overall taste and color of a food product; therefore, careful regulation of processing conditions can play a large role in improving the overall value of plant-based foods.

Combination Technologies in Plant-Based Food Processing

The synergy of combined processing technologies usually offers greater benefits than that of single processing technologies. This principle is known as hurdle technology or combination processing. Combination technologies improve the safety, quality, and efficiency of foods by integrating two or more processing technologies. For example, the combination of mild heat treatment and pulsed electric field treatment is effective for microorganism inactivation and for retaining nutrients and flavor (Parvathy Nayana et al., 2025). Similarly, the combination of ultrasound and thermal processing can accelerate extraction and improve the functionality of proteins. Combination processing can result in an overall reduction in processing time and energy costs, while maintaining product quality. In the extrusion processing of plant-based meat analogues, combination technologies with enzymatic treatments or high-pressure processing are used. Such combinations improve the creation of meat-like fibrous structures. In summary, combination technologies improve the efficiency and flexibility of plant-based food processing and help to overcome the limitations of single processing technologies.

Technological Integration with Consumer Trends and Sustainability

Changing consumer preferences and digital technologies strongly affect food systems. The introduction of regulations and consumer pressure on manufacturers has created a demand for food that is produced sustainably and is transparent and ethically produced. Therefore, Smart Sensors, AI, and digitized monitoring systems in food processing and supply chain management are being integrated. These systems help process and monitor food in real time, identify safety risks and improve quality control throughout the process (Abreu et al., 2023). AI also helps to improve the quality of food attributes, such as texture, taste, and nutritional value. In recent years, food processing has been the focus of regulations aimed at improving energy consumption and reducing negative environmental impacts. Innovative technologies are helping in sustainable food production and improving consumer acceptance of plant-based foods.

Challenges and Future Perspectives

New food processing technologies present a host of opportunities but still face a number of obstacles. The high price of highly specialized equipment is a barrier to entry for small and medium-scale food industries. The industrial-scale implementation of some technologies is still some time away, despite some provisional laboratory-scale testing. The perceptions of consumers and regulatory agencies pose additional obstacles. While regulatory agencies must approve new technologies to ensure their safety for food production, consumers must be comfortable with food produced using these technologies. Future research is needed to ensure the adoption of these technologies. The research in these advanced technologies will improve the efficiency of food processing equipment and develop better industrial unit operation protocols. Better interrelations between scientists, industrial practitioners, and public policy will be instrumental in advancing food processing technologies.

Conclusion

The advancement of food processing technologies significantly enhances the quality, safety, and sustainability of plant-based products. These technologies, including high-pressure processing, pulsed electric fields, ultrasound, and cold plasma, facilitate the modification of plant proteins, improve food functionality and extend shelf life. Additionally, they promote favourable protein–polyphenol interactions, contributing to the development of high-quality plant-based foods. When integrated with digital monitoring systems and sustainable production approaches, these technologies contribute to more efficient and sustainable food systems. Some of the notable challenges include the high cost associated with these technologies, scalability issues and the regulatory constraints within the food industry. However, the advancements in legal frameworks, technological innovation and research are anticipated to address these challenges. The increasing consumer demand for nutritious and sustainable food reflects that food processing technologies will continue to play in the future of plant-based foods.

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Transforming Chocolate Manufacturing: Through Data Science and AI

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Priyanka[1], Pratibha Singh[2]
[1]B.Tech., [2]Associate Professor,
Department of Food Plant Operations, Incubation, and Entrepreneurship, National Institute of Food Technology Entrepreneurship and Management – Thanjavur (NIFTEM-T), Tamil Nadu, India.

Abstract
This article presents how modern data science and Artificial Intelligence (AI) systems, such as artificial neural networks, spectroscopy-based modelling, extreme machine learning models, and kernel distribution models are applied at key processing stages, including fermentation, cracking, drying, refining and conching of chocolate manufacturing. Each complex dataset is processed and converted into predictive models, which are then used as valuable inputs to optimize processing parameters, reduce product variability and human intervention, and improve process efficiency and quality evaluation. Altogether, the application of data science and artificial intelligence in chocolate production makes chocolate production more sustainable and consistent and underlines its increasing significance in determining the future of the cocoa and chocolate industry.

Keywords: chocolate manufacturing, Data science, Artificial intelligence, machine learning.

Introduction
Chocolate manufacturing is a complex, multistage process in which even a minor alteration at each stage of processing can affect the final product quality, taste, and texture of the final product. Fermentation, drying, roasting, conching, and tempering are examples of conventionally significant processes that mainly rely on destructive analytical methods and manual inspection. Since these methods are inconsistent and inadequate, they often lead to product variability and quality losses. These issues have been creatively solved by recent developments in data science, artificial intelligence and machine learning, which have turned conventional production into a data-driven, intelligent production system(Senthil & Janve, 2025).

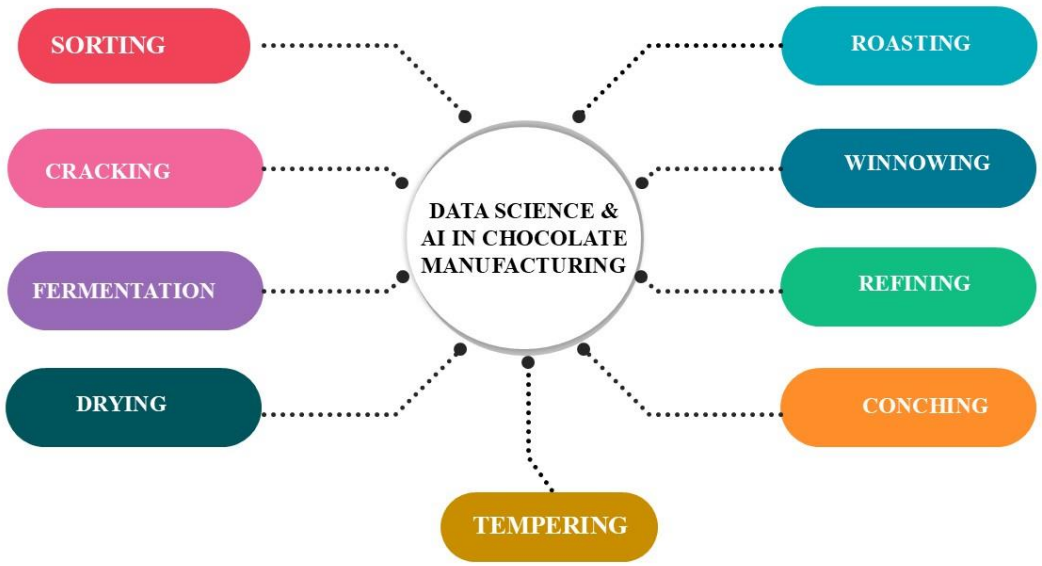
Role of Data Science and AI in Solving Key Processing Challenges in Chocolate Manufacturing
The sorting process is an important part of the cocoa production process, whereby the beans are sorted based on the size, colour and shape in order to ensure only the best beans pass through. Manual sorting is not possible or efficient for large-scale businesses. This is solved using AI-based classification systems. These systems employ cameras or imaging sensors in order to capture visual attributes such as color, form and texture. Upon studying such features, machine learning models predict the beans into acceptable and substandard categories, which makes the process more consistent and productive(Eric et al., 2023). Removal of cocoa beans from the pods is one more labor-intensive process that very often leads to losses of beans during the manual separation. Mechanical cocoa bean extractors have been equipped with Artificial Neural Network (ANN) models to solve this issue. These models can be used to predict optimal working conditions by evaluating parameters like strainer inclination angle, roller speed and pod size. The technique enhances the extraction rate and reduces the loss and damage of beans(Srikanth et al., 2020). Fermentation is critical for flavor development because it leads to the formation of aroma precursors. Traditional evaluation methods are incompetent and detrimental. In order to differentiate fermented and unfermented beans, a non-destructive method using ANN with colorimetric readings (RGB and Lab* values) is designed, and its accuracy is more than 90%(Anggraini et al., 2021; Bagnulo et al., 2024). Fermentation is followed by drying, and the process of drying is heavily dependent on the environmental factors. Fourier Transform Infrared Spectroscopy (FTIR) is combined with supervised machine learning to ensure consistency, which uses Support Vector Machine Regression (SVMR) and Orthogonal Partial Least Squares Discriminant Analysis (OPLS-DA) to oversee data samples and classifications. FTIR produces chemical fingerprints of cocoa samples, and the models predict how drying conditions would influence aroma compounds, which helps in process optimization of drying time and temperature(Bagnulo et al., 2024; Collazos-Escobar et al., 2024). Roasting is necessary to form flavors by Maillard reaction and moisture loss. In some cases, however, small-scale farmers do not have access to sophisticated equipment(van Vliet et al., 2021). The low-cost model involving machine learning and image analysis on a smartphone has been proposed. The accuracy of extraction of the color and texture data and the use of Extreme Learning Machine (ELM) models can categorize roasting levels with a high level of accuracy of 93.75% (Yang et al., 2022). Winnowing the process of separating shells and nibs. This step is largely integrated by an AI-enabled smart processing system(Senthil & Janve, 2025). During refining, the size of the cocoa particle is reduced, and desirable volatiles are developed, which determine the final flavors and taste. The electronic nose (E-nose) systems can be used to optimise refining conditions with the assistance of Kernel Distribution Models (KDM) and Genetic Algorithms (GA) by tracking and predicting volatile behavior(Tan & Kerr, 2019). Conching is hard to monitor because it is a batch-based process, and the processing time of

each batch varies. K-nearest neighbour (KNN) models classify batches as conforming and non-conforming, whereas Dynamic Time Warping (DTW) aligns the time-series process data, enabling real-time quality control(Peres et al., 2020). Finally, tempering controls the crystallization of cocoa butter. ANN models are employed to predict the crystallization behavior and optimize the tempering conditions to reduce the number of defects and increase the product quality(Senthil & Janve, 2025).

Table 1: Types of data and analytical tools used in data-driven chocolate manufacturing:

Data Category	Data Source	Analytical Tool	Purpose	Reference
Colorimetric data	Imaging systems	ANN, classification models	Fermentation and roasting evaluation	(Bagnulo et al., 2024; Yang et al., 2022)
Spectral data	FTIR spectroscopy	SVMR, OPLS-DA	Chemical and aroma profiling	(Bagnulo et al., 2024; Collazos-Escobar et al., 2024)
Time-series data	Sensors, motors	DTW, KNN	Batch alignment and monitoring	(Peres et al., 2020)
Volatile sensor data	Electric nose (E-nose)	KDM, GA	Flavor optimization	(Tan & Kerr, 2019)
Physicochemical data	Thermal and material properties	ANN models	Crystallization behavior prediction	(Senthil & Janve, 2025)

Fig. 1. Integration of Data Science and Artificial Intelligence Across Chocolate Manufacturing Stages:



Challenges and Future Outlook

Although the application of Artificial Intelligence in the chocolate production is on the rise, several challenges persist. These challenges are primarily due to large set-up costs, technical skills and resistance from small-scale manufacturers. The model's accuracy and reliability are affected by variation in processing conditions and the lack of standardised data. However, the future appears promising. The adoption of AI is expected to increase due to advancements in low-cost sensors, smartphone-based technology, and user-friendly AI products. The addition of smart systems and real-time monitoring will enhance process control and the quality of the final product. Overall, AI will play a significant role in developing a more sustainable, efficient and data-driven chocolate manufacturing system(Abraham & Aithal, n.d.).

Conclusion

The integration of data science and artificial intelligence (AI) into chocolate manufacturing has transformed traditional experience-based processing into an intelligent, predictive, and optimized production system. Techniques, such as Artificial Neural Networking-based modelling, spectroscopy combined with machine learning, dynamic time warping, and e-nose systems, have been effectively incorporated into various processing stages, including fermentation, drying, refining, and conching. These systems facilitate precise quality control, minimize product variability, and enhance the

development of flavour precursors, volatile evolution, and cocoa butter crystallisation, all of which collectively determine the final quality of the chocolate. Overall, data science can be utilised to advance the innovation and sustainability within the chocolate production industry, with intelligent processing systems poised to play a pivotal role in shaping the future of cocoa and chocolate production.

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Sustainable Agriculture: A Pathway to a Resilient Future

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Abhishek Singh[1], Mayank Lakhara[1], Swarna[1]
[1]M.Sc. Agronomy Research Scholar, School of Agriculture, Dev Bhoomi Uttarakhand University, Dehradun-248007.

Introduction

In recent years, the urgency for sustainable agriculture has intensified as the world faces pressing challenges such as climate change, population expansion, and dwindling natural resources. Sustainable agriculture represents a comprehensive approach to food production, aiming to meet present demands while safeguarding the capacity of future generations to fulfil their own. This article explores the core principles, practices, advantages, and obstacles linked to sustainable agriculture.

Understanding Sustainable Agriculture

Sustainable agriculture integrates farming systems that are environmentally sound, socially responsible, and economically viable. It encompasses practices designed to improve resource efficiency, strengthen biodiversity, and promote social fairness. The key objectives of sustainable agriculture include:

Food Security: Ensuring that all individuals have consistent access to safe and nutritious food.

Environmental Stewardship: Reducing harmful impacts on ecosystems while fostering ecological health.

Economic Sustainability: Providing support for farmers and strengthening rural communities.

Social Equity: Upholding fair labour standards and encouraging active community involvement.

Key Practices in Sustainable Agriculture

Crop Diversification: Rotating and intermixing crops helps maintain soil fertility, lowers the risk of pests and diseases, and strengthens resilience against climate variability.

Soil Health Management: Techniques such as cover cropping, reduced tillage, and the use of organic amendments foster nutrient-rich soils that retain moisture and support beneficial microbial activity.

Integrated Pest Management (IPM): This approach combines biological, cultural, and selective chemical methods to control pests in ways that are both environmentally responsible and economically feasible.

Water Conservation: Efficient irrigation systems, including drip irrigation and rainwater harvesting, reduce water consumption while safeguarding vital water resources.

Agroforestry: Incorporating trees into farming and livestock systems enhances biodiversity, captures carbon, and can provide farmers with additional income streams.

Organic Farming: By avoiding synthetic chemicals, this system relies on natural processes to manage pests and diseases while improving soil fertility.

Benefits of Sustainable Agriculture

Environmental Well-being: By improving soil quality, conserving water, and protecting biodiversity, sustainable practices contribute to a healthier and more balanced environment.

Economic Stability: Through income diversification and reduced reliance on external inputs, sustainable farming helps farmers withstand market volatility and adapt to climatic challenges.

Social Advantages: This approach promotes fair labour conditions and strengthens community ties, ensuring that all participants in the agricultural system benefit equitably.

Food Security and Nutrition: Sustainable methods support the production of diverse crops and livestock, resulting in reliable access to safe, nutrient-rich food.

Challenges to Implementation

Economic Constraints: Transitioning to sustainable methods often requires high upfront investment. Small-scale farmers, in particular, struggle to secure financing and access competitive markets.

Knowledge and Training Gaps: Limited awareness and insufficient education about sustainable practices hinder their widespread adoption among farming communities.

Policy Limitations: Existing policies and subsidies frequently favour conventional agriculture, making it difficult for sustainable approaches to gain an equal footing.

Climate Vulnerability: Ongoing shifts in weather patterns pose significant risks to sustainable farming systems, which demand continuous innovation and adaptation.

Conclusion

Sustainable agriculture is not just a farming technique but a comprehensive approach to developing resilient food systems that serve the environment, economy, and society. Sustainable Agriculture is not just a farming technique but a comprehensive strategy for developing resilient food systems that are ecologically, economically, and socially sustainable. Farmers, policymakers, researchers, and consumers must collaborate to address the challenges and promote sustainable agricultural practices. Together, we can create a sustainable future for agriculture that will satisfy everyone's needs.

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The "Drone Didi" Revolution: AI Takes, Command in Wheat Fields

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Ritesh Kumar Bhakat[1]
[1]M.Sc. Agronomy Research Scholar, School Of Agriculture, Dev Bhoomi Uttarakhand University, Dehradun-248007.

Introduction

Traditional wheat farming has long faced a number of issues, including low operational efficiency, excessive chemical inputs, unpredictable pest infestations, and growing labor shortages. These difficulties not only diminish productivity but also contribute to environmental deterioration and increased agricultural expenditures.

To address these difficulties, the "Drone Didi" program was launched in 2023, empowering rural women to operate modern drone-based agricultural services. This program is led by Department of Agriculture and Farmers Welfare. This program is transforming wheat cultivation by combining artificial intelligence (AI) and drone technologies. Notably, AI-powered drones with machine vision have shown the potential to reduce pesticide use by 30-50% while increasing wheat yields, indicating a big step toward sustainable agriculture.

Technology: What's Under the Hood?

The Drone Didi revolution is effective because of its advanced technology framework. Modern agricultural drones are outfitted with multispectral sensors that may detect changes in crop health, such as nutrient deficits and water stress, long before visible symptoms appear to the naked eye. These sensors collect detailed images at multiple wavelengths, allowing for exact crop analysis.



Source: krishijagran.com

Furthermore, Artificial Intelligence and Machine Learning (ML) algorithms use neural networks to evaluate these images, enabling for the accurate detection of diseases like yellow rust, which is a huge threat to wheat production. Early detection ensures timely intervention, preventing widespread damage. Another critical component is Variable Rate Technology (VRT), which allows drones to spray fertilizers and insecticides only where they are needed. This tailored method minimizes chemical waste, lowers expenses, and improves input efficiency.

Impact on Wheat Productivity and Sustainability

The combination of AI and drone technologies has resulted in dramatic increases in wheat output and sustainability. Farmers now have real-time, data-driven information to help them make decisions about irrigation, fertilization, and pest management. This precision farming strategy makes the best use of resources, resulting in healthier crops and higher yields. Precision spraying with drones not only increases efficiency but also lowers farmers' direct contact to dangerous chemicals, enhancing occupational safety.

Furthermore, it reduces environmental degradation caused by excessive chemical runoff. Recent adoption between 2024-2025 in major wheat-growing regions has demonstrated favorable trends, including improved crop health, higher grain quality, and increased overall productivity. These improvements underscore drone technology's potential for transforming conventional farming into a more sustainable and efficient system.

Overcoming Challenges in Adoption

Despite its benefits, the use of drone technology in agriculture confronts some hurdles, most notably the high initial cost of equipment and the requirement for technical competence. However, government efforts such as the Namo Drone Didi plan have played an important part in overcoming these obstacles by giving subsidies and financial assistance. Training programs are also being implemented to provide rural women and farmers with the knowledge required to operate and maintain this modern machinery. As a result, the effort not only encourages technological adoption, but also skill development and entrepreneurship in rural communities.

Key Features of the Namo Drone Didi Schemes

1. 80% subsidy on drone costs up to 8 lakhs.
2. Loan facility from AIF for the remaining cost at a 3% interest rate.
3. Drone pilot training as part of the drone package.
4. Opportunity for SHGs to earn additional income of at least Rs. 1 lakh per year through drone services.

Conclusion

The "Drone Didi" revolution represents a significant intersection of technology, sustainability, and social empowerment. By utilizing AI-powered drones in wheat farming, it addresses long-standing agricultural issues while promoting efficient resource use and environmental conservation. At the same time, it empowers rural women by introducing them to new options in modern agriculture. As this effort grows, it has the prospect of making wheat production a smarter, safer, and more sustainable process in the future.

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Weed Specific Herbicide Application Using Sensor-Based Sprayers: A Smart Approach for Sustainable Weed Management

Article ID: 73552

Mayank Lakra[1], Swarna[1]

[1]M.Sc. Agronomy, School of Agriculture, Dev Bhoomi Uttarakhand University, Dehradun PIN-248007.

Introduction

Weeds pose a significant challenge in agriculture, as they grow alongside crops and compete for essential resources such as nutrients, water, sunlight, and space. This competition ultimately leads to a decline in both crop yield and quality. Traditionally, farmers have managed weeds by applying herbicides across their entire fields. However, this approach has several drawbacks, including increased farming costs, environmental impacts, and potential harm to crops. In recent years, innovative technologies have emerged to address these issues. One such advancement is the use of sensor-based sprayers for targeted herbicide application. This technique involves applying herbicides only in areas where weeds are detected, rather than across the entire field. By doing so, it not only reduces costs but also minimises chemical usage and helps safeguard the environment.

What is the Senor-Based Sprayer?

A sensor-equipped sprayer is an advanced machine designed to identify weeds in agricultural fields and apply herbicide exclusively to those locations. It utilises sensors, specialised devices, to recognise green plants or unwanted weeds. When a weed is detected, the sensor transmits a signal to the nozzle of the sprayer, prompting it to release herbicide only at that specific spot. In the absence of weeds, the sprayer refrains from dispensing any chemicals. This approach enhances both the efficiency and accuracy of the spraying process.

How does It Function?

The operation of a sensor-based sprayer is straightforward and can be broken down into several steps: Detection: Sensors survey the field, recognizing weeds by their colour, shape, or reflectivity. Signal Processing: The system evaluates this data to determine if the plant in question is a weed. Targeted Spraying: When a weed is identified, the nozzle applies herbicide precisely to that location. No Spray on Clean Areas: If no weeds are detected, the sprayer remains inactive, conserving herbicide. This entire sequence occurs rapidly as the machine traverses the field.

Various Types of Sensors are Employed in These Sprayers

Optical sensors recognise green plants by measuring light reflection. Infrared sensors determine the presence of plants by analysing variations in heat or light. Camera-based sensors rely on images to differentiate between crops and weeds. Lastly, AI-based sensors utilize artificial intelligence to enhance the precision of weed detection.

Advantages of Sensor-Based Sprayers

This technology provides many benefits:

Reduced Herbicide Use: Only weeds are sprayed, so chemical use is reduced by 40–80%.

Cost Saving: Farmers spend less money on herbicides.

Environmental Protection: Less chemical use means less pollution of soil and water.

Crop Safety: Since herbicides are not sprayed everywhere, crops are less affected.

Reduced Herbicide Resistance: Overuse of herbicides causes resistance in weeds. This method helps reduce that problem.

Limitations of Technology

Despite many advantages, there are some limitations:

High Initial Cost: These machines are expensive for small farmers.

Technical Knowledge Required: Farmers need training to use and maintain the system.

Difficulty in Dense Crops: It may be difficult to identify weeds when crops are closely spaced.

Power Requirement: Requires electricity or battery support

Observations

Herbicide Use:

Traditional method: Full field spraying
Sensor-based method: About 50–60% less herbicide used

Weed Control Efficiency:

Both methods-controlled weeds effectively
Sensor-based spraying showed similar weed control as the traditional method

Cost of Spraying:

The sensor-based method reduced the chemical cost significantly
Overall saving: Around 30–40%

Crop Growth:

Wheat crops in sensor-based areas showed better growth.
Less chemical stress on crop plants.

Farmer Experience

The farmer reported that:

The machine saved time and labour
Less herbicide was required
Crop health improved
The initial cost of the machine was high, but beneficial in the long term.

Conclusion of Case Study: This case study demonstrates that sprayers equipped with sensors provide an efficient and cost-effective approach to managing weeds in wheat crops. They minimise herbicide application, decrease expenses, and safeguard the environment, all while maintaining crop productivity.

Future Prospects: The advancement of weed management is set to evolve with precision agriculture. Integrating sensor-equipped sprayers with various technologies can enhance efficiency. This includes utilising drones for aerial application, employing GPS for targeted spraying, leveraging mobile applications for instant monitoring, and applying artificial intelligence to improve weed detection. As technology progresses, the prices of these devices are expected to drop, allowing a greater number of farmers to utilise them effectively.

Conclusion

The application of weed-specific herbicides through sensor-driven sprayers is an intelligent and sustainable approach for contemporary agriculture. This method minimises herbicide consumption, reduces expenses, and safeguards the environment. Despite facing certain challenges, the advantages far outweigh them. This innovative technology signifies the future of weed control and can significantly contribute to enhancing crop yields while ensuring environmental protection.

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Farming for Healthy Food and Environment: A Step Towards Sustainability

Article ID: 73553

Sachin Singh[1], Vikash Kumar[1]
[1]M.Sc. Agronomy Research Scholar, School of Agriculture, Dev Bhoomi Uttarakhand University, Dehradun-248007.

Introduction

Agriculture is the backbone of human survival, yet conventional farming practices have increasingly contributed to environmental degradation, soil depletion, and health concerns due to excessive chemical use. In recent years, the concept of farming for the environment and healthy food has gained global attention as a sustainable alternative. This approach integrates ecological principles with agricultural practices to produce safe, nutritious food while preserving natural resources. Sustainable farming systems aim to balance productivity with environmental conservation, ensuring long-term food security and ecosystem health.

Concept of Environment-Friendly Farming

Environment-friendly farming, often referred to as sustainable or ecological agriculture, focuses on minimizing environmental impact while maintaining soil fertility and biodiversity. It includes practices such as:

1. Organic farming (avoiding synthetic fertilizers and pesticides)
2. Conservation agriculture (minimal tillage, crop rotation)
3. Agroforestry (integration of trees with crops and livestock)
4. Integrated pest management (IPM)

These practices reduce pollution, enhance soil structure and promote biodiversity making agriculture more resilient to climate change.

Healthy Food Production

Healthy food production is closely linked with sustainable farming systems. Crops grown under environmentally friendly conditions are:

1. Free from harmful chemical residues
2. Rich in essential nutrients
3. Safer for human consumption

Organic fruits, vegetables, and grains often contain higher levels of antioxidants and micronutrients. Additionally, reducing chemical inputs helps prevent long-term health issues such as cancer, hormonal imbalance, and neurological disorders.

Environmental Benefits of Sustainable Farming

1. Soil Health Improvement: Sustainable practices enhance soil organic matter, improve microbial activity, and prevent erosion.

2. Water Conservation: Efficient irrigation methods like drip and rainwater harvesting reduce water wastage.

3. Biodiversity Conservation: Mixed cropping and agroforestry support diverse plant and animal species.

4. Climate Change Mitigation: Carbon sequestration in soil and reduced greenhouse gas emissions help combat climate change.

Socio-Economic Benefits

1. Improved farmer income through premium prices for organic produce
2. Reduced input costs due to minimal chemical usage
3. Employment generation in rural areas
4. Enhanced food security and nutrition

Challenges in Implementation

Despite its benefits, sustainable farming faces several challenges:

1. Initial lower yields during transition period
2. Lack of awareness and technical knowledge
3. Limited market access for organic products

4. Certification and policy barriers

Addressing these challenges requires government support, farmer training, and improved market linkages.

Strategies for Promotion

1. Awareness programs and farmer education
2. Subsidies and incentives for sustainable practices
3. Strengthening organic supply chains
4. Research and innovation in eco-friendly technologies
5. Policy support for sustainable agriculture

Conclusion

Farming for the environment and healthy food is essential for achieving sustainable development and ensuring the well-being of future generations. By adopting eco-friendly agricultural practices, it is possible to produce nutritious food while preserving natural resources and maintaining ecological balance. Although challenges exist, coordinated efforts from farmers, governments, researchers, and consumers can transform agriculture into a sustainable and health-oriented system. This approach not only supports environmental conservation but also promotes human health, economic stability, and social equity.

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Applications of Marker-Assisted Selection in Crop Improvement

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S Amisha Sharma[1]
[1]M.Sc. Genetics and Plant Breeding Research Scholar, School of Agriculture, Dev Bhoomi Uttarakhand University, Dehradun-248007.

Molecular tools have made great progress in plant breeding in recent years. Marker-assisted selection (MAS), which uses DNA markers to pick plants with desired features, is one of the most significant methods. MAS is quicker, more precise, and less affected by environmental factors than conventional breeding techniques. The fundamental idea of MAS, its guiding principles, its main uses in crop development, its benefits and drawbacks, and its possibilities for the future are all covered in this review.

Introduction

Plant breeding plays an important role in improving crop productivity, quality, and resistance to biotic and abiotic stresses. Traditionally, plant selection has been based on observable traits, but this process is time-consuming and often influenced by environmental conditions. Due to these limitations, molecular breeding approaches such as marker-assisted selection (MAS) have become increasingly important. MAS involves selecting plants based on molecular markers that are closely linked to desirable genes, allowing identification of superior genotypes at an early stage of development. This makes the breeding process more efficient and reliable.

Principle of Marker-Assisted Selection

The principle of MAS is based on the genetic linkage between DNA markers and target genes. When a marker is closely associated with a gene controlling a particular trait, the presence of the marker indicates the presence of that gene. This allows breeders to select plants based on their genotype rather than phenotype. Since DNA markers are not affected by environmental factors, they provide more consistent and accurate results. As a result, MAS improves the efficiency of breeding programs by reducing the time required for selection.

Types of Molecular Markers Used in MAS

Various types of molecular markers are used in MAS, including restriction fragment length polymorphism (RFLP), random amplified polymorphic DNA (RAPD), simple sequence repeats (SSR), and single nucleotide polymorphism (SNP). Among these, SSR and SNP markers are widely preferred due to their high reproducibility, co-dominant nature, and wide distribution across the genome. These markers play a crucial role in identifying genetic variation and selecting desirable traits in crop plants.

Applications of MAS in Crop Improvement

Marker-assisted selection has several important applications in crop improvement. One of the major applications is in developing disease-resistant varieties. MAS helps in identifying and transferring resistance genes into crop plants, which leads to the development of varieties with improved resistance to diseases such as bacterial blight in rice and various fungal infections in other crops .Another important application is in improving tolerance to abiotic stresses such as drought, salinity, and extreme temperatures. These traits are usually controlled by multiple genes, making them difficult to improve through conventional breeding. MAS helps in identifying quantitative trait loci (QTLs) associated with these traits and selecting plants carrying these genes efficiently.

In addition, MAS is used for improving yield, which is a complex trait influenced by many genetic and environmental factors. By identifying and selecting genes associated with yield, MAS increases the efficiency of breeding programs and accelerates the development of high-yielding varieties. It is also widely used for quality improvement, including enhancing nutritional content such as proteins, vitamins, and minerals. This is particularly important in biofortification programs aimed at improving human health. Another significant application of MAS is gene pyramiding, where multiple genes for desirable traits are combined into a single variety. This approach helps in developing crops with durable resistance and better performance. Furthermore, MAS is useful in hybrid breeding programs, where it helps in identifying suitable parental lines and maintaining genetic purity of hybrids.

Advantages of MAS

Marker-assisted selection offers several advantages over conventional breeding methods. It allows selection at an early stage of plant growth, reducing the time required for breeding. It is not affected by environmental conditions, which increases the accuracy and reliability of selection. MAS also helps in saving time, labor, and resources, especially when dealing with complex traits. Due to these advantages, MAS has become an essential tool in modern plant breeding.

Limitations of MAS

Despite its many advantages, MAS also has some limitations. The technique requires expensive equipment and well-equipped laboratories, which may not be available in all regions. It also requires skilled personnel to perform molecular analysis. In some cases, suitable markers may not be closely linked to the desired traits, reducing the effectiveness of selection. Additionally, MAS is less effective for traits controlled by a large number of genes, as it becomes difficult to track all the contributing factors.

Future Prospects

The future of marker-assisted selection is very promising. With the advancement of genomic technologies, high-throughput genotyping, and bioinformatics tools, MAS is becoming more efficient and cost-effective. The integration of MAS with modern techniques such as genomic selection and gene editing will further enhance crop improvement programs. It will play a key role in developing climate-resilient, high-yielding, and nutritionally improved crop varieties, which are essential for ensuring global food security.

Conclusion

In conclusion, marker-assisted selection is a powerful and efficient approach in modern plant breeding. It allows precise and early selection of desirable traits, making the breeding process faster and more reliable. Although there are some limitations, continuous advancements in molecular technologies are likely to overcome these challenges. Therefore, MAS will continue to play an important role in improving crop productivity and sustainability in the future.

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Wheat Straw Management: From Burning Problem to Economic Opportunity

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Swarna[1], Mayank lakra[1], Umasri[1], Suraj Luthara[2]

[1]M. Sc (Agronomy) Student, School of Agriculture, Dev Bhoomi Uttarakhand University, Dehradun, India, PIN- 248007.

[2]Assistant Professor, School of Agriculture, Dev Bhoomi Uttarakhand University, Dehradun, India PIN- 248007.

Introduction

Wheat stands as one of India's key agricultural products. Following the harvest, a significant quantity of straw is left behind in the fields, commonly referred to as crop residues. To swiftly prepare the land for the subsequent planting, many farmers resort to burning this leftover straw. Unfortunately, this practice poses a significant environmental challenge, negatively affecting human health and reducing soil fertility. However, it is crucial to recognise that wheat straw should not be viewed as waste; rather, it is a valuable asset. With appropriate management, it has the potential to generate income for farmers.

Stubble Burning: A Major Problem

Stubble burning is frequently observed in regions such as Punjab, Haryana, and Western Uttar Pradesh. Farmers opt for this method due to its quickness and cost-effectiveness.

Harmful Effects of Burning

Air pollution and smog are significant issues. They can cause respiratory problems in both humans and animals. Additionally, pollution depletes essential nutrients in the soil and harms beneficial microorganisms. It also contributes to the acceleration of global warming. Although burning materials might seem like a time-saving solution, it ultimately inflicts lasting harm on the environment and agricultural practices.

Why is Wheat Straw Valuable?

Wheat straw is composed of valuable elements such as cellulose and organic material. Rather than being burned, it can be utilised in various beneficial ways. Effectively utilising straw contributes to enhancing farmers' earnings, boosting soil health, and minimising pollution.

Economic Uses of Wheat Straw

Animal Fodder: Wheat straw is commonly utilised as cattle feed. It can be combined with fresh fodder or processed to enhance its nutritional content. This approach allows farmers to lower their feed expenses.

Biofuel Production: Wheat straw serves as a source for producing various forms of energy, including biogas, bioethanol, and biomass energy. Biofuels derived from these materials offer a renewable energy alternative, helping to decrease our reliance on fossil fuels. Numerous industries are increasingly utilising straw to produce electricity and heat. These sustainable fuels not only benefit the environment but also contribute to minimising our dependence on traditional fossil fuel sources.

Compost And Organic Manure: Straw can be broken down to create compost, which enhances soil fertility and lessens the reliance on chemical fertilisers. Composting one ton of wheat straw typically yields approximately 200-250 kilograms of premium organic compost.

Mulching: Farmers apply straw as a form of mulch to protect the soil. This practice helps retain moisture, inhibit weed growth, and enhance the structure of the soil. Straw mulch is particularly advantageous in areas where rainfall is inconsistent.

Industrial Uses: Wheat straw serves various industrial purposes, including the production of paper and cardboard. It is also utilised in creating packaging materials. Additionally, eco-friendly tableware and mats are manufactured from straw, supporting sustainable options to replace plastic products.

Modern Technologies for Straw Management: Governments and agricultural research institutions are advocating for the use of machines and technologies to effectively handle straw.

Happy Seeder Machine: Plant wheat directly in fields that have leftover straw. This approach eliminates the need to burn straw, thereby saving both labour and time.

Super Straw Management System (SMS): Cuts and evenly distributes straw across the field. Creates a narrow channel for seed placement. Maintains mulch between crop rows. Promotes soil health while getting the land ready for the upcoming crop.

Baling Machines: Gather straw into bales for transportation to various industries or for use as animal feed.

Government Support

Sub-Mission on Agricultural Mechanisation: The Ministry of Agriculture and Farmers Welfare launched SMAM to promote farm mechanisation.

40-50% subsidy for individual farmers.

Up to 80% subsidy for groups and cooperatives.

Crop Residues Management (CRM): The CRM initiative is specifically crafted to address the issue of stubble burning in northern regions such as Punjab, Haryana, and Uttar Pradesh. It advocates for in-situ management, which involves incorporating straw back into the soil. To further this aim, the Ministry of Agriculture and Farmers Welfare has introduced the SMAM program to encourage the mechanisation of farming practices. Additionally, the program supports ex-situ management, where straw is utilised in various industries. It also offers financial assistance for purchasing machinery and implements awareness campaigns to educate farmers.

State Government Support: State governments are essential for effective implementation. For instance, the Uttar Pradesh Government offers various initiatives, including subsidies of up to 50% on equipment for straw management. They also provide user-friendly online application processes and support specifically aimed at small and marginal farmers.

Case Studies and Examples

Punjab- Punjab has been grappling with significant air pollution stemming from the burning of wheat and paddy straw. However, farmers in the region who have implemented the Happy Seeder have managed to cut down on stubble burning by more than 50%. This innovative approach has not only enhanced soil fertility but has also provided farmers with additional revenue through the sale of straw. By opting out of manual residue removal, these farmers have realised savings of Rs3,000 to Rs4,000 per hectare. This shift not only contributes to environmental benefits but also supports farmers' financial well-being.

Haryana: In Haryana, the implementation of the Super Straw Management System has facilitated the chopping and even distribution of straw across the fields. This approach has led to a 15-20% increase in soil organic matter, allowing for timely planting without the need for burning. Additionally, it has lowered tillage expenses and boosted the yield potential for subsequent crops.

Centres, allowing farmers to rent machinery such as Happy Seeders, Mulchers, and Balers. In Western Uttar Pradesh, farmers have started selling wheat straw to biomass power plants, receiving between Rs 1500 and Rs 2000 per ton. Additionally, local entrepreneurial groups are transforming this straw into mushroom substrate, compost, and fodder, which creates further income opportunities.

Environmental and Economic Benefits

Minimise Air Pollution: Promoting cleaner air leads to improved health outcomes for communities.

Improve Soil Fertility: Boosts the organic matter content, resulting in greater crop yields.

Create Extra Income: Farmers can earn additional revenue by selling straw for animal feed, fuel, or industrial applications.

Foster Sustainable Agriculture: Encourages environmentally friendly farming methods and ensures long-term productivity on farms.

Challenges Faced by Farmers

While there are advantages, several obstacles persist. The expense of machinery remains high, and there is often a lack of awareness regarding available resources. Additionally, access to technology is limited, and the short intervals between crop cycles pose difficulties. Addressing these concerns requires adequate support and effective solutions.

Conclusion

Wheat straw should not be regarded merely as agricultural waste; it actually represents a valuable resource with both economic and environmental benefits. By implementing effective management practices, farmers can safeguard the environment, enhance soil fertility, and generate additional income.

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Millet for Climate- Resilient Agriculture

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Nidhi Kumari[1], Umasri Dudipala[1]
[1]M.Sc. Agronomy Research Scholar, School of Agriculture, Dev Bhoomi Uttarakhand university, Dehradun.

Climate change significantly threatens global food security by reducing yield quality and quantity both. Erratic rainfall, increasing temperature, frequent drought and increased co2 level are affecting crop productivity. In such condition, Climate -resilient crop plays a vital role in sustainable Agriculture. Millet are considered as most climate resilient crop because of their capability to grow even in rigorous environmental condition. This crop requires less water, tolerate to high temperature and can grow well in less fertile or poor soil where other crops fail. Owing to their unique characteristics, it is recognized as an important component of climate-smart agriculture.

Significance of Millet in Sustainable Agriculture

Millet are small-seeded and among most domesticated cereals that have been cultivated in India for centuries. There are many types of millet that are cultivated in our country e.g. finger millet also known as Ragi, pearl millet, foxtail millet and sorghum. Millet are highly adaptable and it can be grown in arid and semi-arid region. One of the major advantages of millet that it requires very less water compared to wheat and rice. Bajra is Highest Drought tolerant among millet. Among the cereals water requirement of Bajra is lowest (250-500mm) but sensitive to water logging. Millet also contribute in soil health it`s Deep rooted system improve soil structure and conserves soil moisture. In addition, millet require very less chemical fertilizer or inputs, which plays a big role in sustainable farming.

Millet and Climate Resilience

Millets play a significant role in climate-resilient agriculture due to many important characteristics:

1. **Short duration crop:** many varieties of millet mature in less period.
2. **Low input requirement:** millets require less fertilizer, herbicides, pesticides and water as well.
3. **Drought tolerance:** millet can grow even in less water and are tolerant to moisture stress condition.

Economic and Nutrition Value

Millet are known as powerhouse of nutrition due to following reason:

1. Low Glycaemic index: mostly millet are low in GI, it manages blood sugar that reduces the type 2 diabetes.

2. Vitamins and minerals: it is rich source of vitamin like niacin, B-complex, B6 and folic acid & minerals like iron & calcium.

3. Millet fulfil the requirement of protein (7-12%), magnesium, antioxidant, phosphorus and dietary fibre as well.

4. From farmer`s and global marketing prospective, millet offer many economic advantages-

5. Millet are short period crop, many varieties complete their life cycle in 2-3 months generally.it offers value addition opportunities for entrepreneurs due to its growing demand of processed product like (chips, cookies and noodles) in market.

Millet plays a vital role in sustaining biodiversity along with providing essential vitamins and minerals for human health. Viewing it`s unique characteristics of sustainability and farmer`s friendly millet cultivation is being promoted India, it directly supports the marginal farmer especially in water stress condition. Millet can be integrated with dry land farming, crop rotation, mixed farming and in multi-storied cropping, there is one more fact about millet crop (*sorghum bicolor)* that it acts as allelopathy plant due to its production of phytotoxin naturally known as sorgoleone, which inhibit the germination of weed species. Inclusion of millet can increase the income stability of farmers and reduce the dependency on water-intensive crop. Promoting and Encouraging farmers for millet farming or millet-based farming can improve soil health, Income generation and will contribute to climate change adaptation.

Government Initiative for Millet

Observing the special characteristics of millet Government of India has taken several initiatives to promote cultivation, production and consumption in India. United National General Assembly declared 2023 as the international year of millet due to its high vitamin and mineral content and naturally gluten free. Millet's cultivation has been supported through the National food security and nutrition mission to boost millet production. "Chhattisgarh-Millet Mission" in 2021 Government of Chhattisgarh launched this mission to become Heart of millet cropping, to improve productivity of Ragi, Kodo, and Kutki.

Conclusion

Millet is a miracle crop and act as a Boon to biodiversity. As a climate-resilient crop, it has capability to grow in harsh condition with no pesticides, less fertilizer input and less water requirement which make it captivating for Researchers and farmers. Promoting millet cropping can improve soil fertility, productivity, water conservation and inhibit the growth of weeds.

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AI- Driven Precision Farming: The Future of Agronomy

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Ravi Parkash Kumar[1]
[1]M.Sc. Agronomy Research Scholar, School of Agriculture, Dev Bhoomi Uttarakhand University, Dehradun-248007.

Introduction

One of the most fundamental and ancient human endeavors, agriculture is changing dramatically in the twenty-first century. Farmers are under unprecedented pressure to boost output while preserving environmental sustainability as the world's population is expected to surpass 9 billion people by 2050. Conventional farming methods, which frequently depend on treating fields consistently and making decisions based on intuition, are longer enough to handle these expanding difficulties. In this regard, AI-driven precision farming has surfaced as a ground-breaking strategy that is transforming agronomy going forward. AI's capacity to provide farmers with predictive capabilities is another significant facet of agriculture. Farmers may predict weather patterns, market trends, and crop performance with sophisticated forecasting models. This lowers risks related to uncertainty by enabling them to more efficiently plant planting, harvesting, and distribution. Furthermore, automation technologies like autonomous machinery and AI- powered robots are boosting operational efficiency and decreasing reliance on labor, especially in areas where there is a labor shortage.

What is Precision Farming?

Precision farming, often known as precision agriculture, is the use of advanced technologies to track, analyses, and manage agricultural activity with great accuracy.

Farmers may make more educated judgements about their fields by combining Artificial Intelligence (AI) with resources like satellite imaging, sensors, drones, GPS systems, and data analytics. Precision farming, unlike traditional approaches, recognizes variations in soil qualities, moisture levels, crop health, and insect infestation, allowing for focused interventions that maximize resource utilization and crop output.

Furthermore, AI- driven precision farming promotes resource conservation, which contributes to sustainable agricultural practices, Water scarcity, soil degradation, and climate change are all serious challenges that jeopardize global food security. AI technologies contribute to these concerns by enabling more efficient water management, minimizing chemical usage, and enhancing soil health.

Key Technologies Driving AI Precision Farming Internet of Things (IoT) Sensors & Drones and Satellite Imaging

Smart sensors installed in fields capture real- time information on soil moisture, temperature, and nutrient levels. This constant data stream feeds AI systems, allowing for dynamic decision- making, and aerial imagery gives extensive information about crop health and field variability. Drones equipped with multispectral cameras can detect stress regions that are unseen to the naked eye.

Machine Learning Models & Autonomous Machinery

Machine learning algorithms use both historical and real- time data to anticipate events and recommend actions. These models evolve over time, becoming more precise with each growing season, and self- driving tractors and robotic harvesters use artificial intelligence to conduct jobs with more precision and efficiency, decreasing labor dependency and operational expenses.

Benefits of AI-Driven Precision Farming Increase

Productivity & Resource efficiency: Farmers may maximize yields while using fewer resources by optimizing inputs and decreasing waste, and water fertilizer, and insecticides are only used where necessary, reducing environmental effect.

Cost Reduction and Sustainability: Over time, automation and efficient resource use reduce operating costs, and by limiting chemical usage and maintaining soil health, precision farming promotes environmentally sustainable practices.

Climate Resilience: AI helps farmers adapt to climate variability by providing predictive insights and risk assessments.

Obstacles and Restriction

AI- driven precision farming has a number of obstacles despite its potential:

High Initial Costs & Data Accessibility: For small- scale farmers in particular, sophisticated equipment and software can be costly, and in rural locations, dependable data gathering and internet connectivity are not always available.

Technical Expertise and Data privacy issues: To use AI tools efficiently, farmers require training, and there are still unanswered questions about who owns and uses agricultural data. Addressing these challenges will be critical to ensuring equitable access to these technologies.

The Role of Artificial Intelligence in Agriculture

Artificial Intelligence (AI) is essential to this shift. Artificial intelligence systems can process massive volumes of agricultural data, such as weather patterns, soil conditions, crop health, and market trends. Through techniques such as machine learning and computer vision.

AI Allows Farmers to

1. Estimate crop yields with excellent accuracy
2. Identify diseases and pests early
3. Optimize irrigation and fertilization
4. Automate labor-intensive tasks.

Emerging Trends Include

Predictive Farming & Digital farm twins: Using AI to estimate outcomes before planting begins, and virtual replicas of farms to evaluate ideas without real- world risks.

AI-Powered Market Insights: Helping Farmers Decide **What to Grow** Based on Demand. Governments, academic institutes, and commercial enterprises are investing extensively in AI agriculture solutions, indicating a promising future for growth and innovation.

Conclusion

AI-powered precision farming promises a game-changing revolution in agriculture, providing solutions to some of the world's most serious issues, such as food security, climate change, and resource scarcity.

Farmers may achieve a more productive, sustainable, and resilient future by embracing the power of Artificial Intelligence.

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Role of Quantitative Trait Loci (QTL) Mapping in Crop Improvement

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Nitish Kumar[1]
[1]M.Sc. Genetics and Plant Breeding Research Scholar, School of Agriculture, Dev Bhoomi Uttarakhand University, Dehradun-248007.

Introduction

Rapid population increase, climate change, and rising demand for food, feed, and bio-based goods present hitherto unheard-of difficulties for global agriculture. Therefore, increasing crop resilience and production has emerged as a key objective of contemporary plant breeding initiatives. However, the majority of agronomically significant traits, including yield, stress tolerance, and quality attributes, are quantitatively inherited and controlled by several genes with minor effects, making it difficult and time-consuming to increase them using traditional breeding methods.

One important method for locating genomic areas linked to phenotypic variation in complex characteristics is Quantitative Trait Loci (QTL) mapping. To identify the genomic areas governing trait expression, QTL mapping uses statistical correlations between molecular markers and phenotypic traits. The resolution and efficiency of QTL discovery have greatly increased over the past ten years with to developments in high-throughput genotyping, next-generation sequencing (NGS), and bioinformatics tools. This has made it possible to identify stable and major-effect loci across a variety of crop species.

Concept of Quantitative Traits and QTLs

A statistical and genetic method for locating genomic areas linked to quantitative traits is called QTL mapping. It is based on the idea of genetic linkage, which states that genes or markers that are close to one another on a chromosome typically inherit together. Researchers can identify certain genomic regions governing trait variation by examining the relationship between molecular markers and phenotypic traits in a mapping population. The accuracy and dependability of QTL detection have significantly increased with the use of molecular markers including SSRs, SNPs, and AFLPs.

Importance in Understanding Complex Traits

In order to understand the genetic structure of complex traits, QTL mapping is essential. Numerous genes with negligible individual effects regulate traits including grain yield, drought tolerance, disease resistance, and nutrient usage efficiency. These genes can be identified and their interactions—including additive, dominance, and epistatic effects—understood with the aid of QTL analysis. With this information, breeders may create successful breeding plans and make well-informed decisions.

Role in Marker-Assisted Selection (MAS)

Marker-Assisted Selection is one of the most important uses of QTL mapping. Closely related DNA markers can be used to select plants with desired features without waiting for complete phenotypic expression after QTLs connected to those qualities have been found. This lessens the impact of environmental unpredictability, speeds up the breeding process, and increases the accuracy of selection. MAS is especially helpful for characteristics that are expensive, time-consuming, or challenging to quantify.

Gene Pyramiding and Development of Superior Varieties

Gene Pyramiding, the process of combining several advantageous genes into a single genotype, is made easier by QTL mapping. This strategy is particularly crucial for creating crop varieties that are tolerant of various abiotic stresses and have long-lasting resistance to pests and diseases. Breeders can create superior cultivars with improved performance and stability by mixing multiple QTLs.

Role in Improving Yield and Quality Traits

Yield is a very complicated variable that is impacted by a number of component factors, each of which is governed by a distinct QTL. Breeders can find genetic areas linked to yield components including grain quantity, size, and weight by using QTL mapping. Similarly, by focusing on particular QTLs, quality attributes including protein content, oil composition, and micronutrient levels can also be enhanced. As a result, high-yielding and nutritionally enhanced crop types are created.

Understanding Genotype × Environment Interaction

Environmental factors have a substantial impact on the expression of quantitative traits, resulting in Genotype × Environment Interaction. QTL mapping facilitates the identification of both environment-specific and environment-stable QTLs. This is accomplished by assessing mapping populations in various environmental settings and examining the consistency of QTL expression. While environment-specific QTLs can be employed to create variety suited to particular places, stable QTLs are very beneficial for developing globally adaptable kinds. Comprehending the G×E interaction is crucial for enhancing crop performance in climatically changing environments and guaranteeing yield stability.

Advancements in QTL Mapping Techniques

The efficiency and resolution of QTL mapping have been greatly improved by recent developments in genomic technologies. The usage of thousands of markers throughout the genome is now possible thanks to high-throughput sequencing and genotyping systems, improving mapping accuracy. In contrast to classical linkage mapping, methods like genome-wide association studies (GWAS) use historical recombination events and natural populations to attain higher resolution. The benefits of both linkage and association mapping are combined in nested association mapping (NAM). Furthermore, QTL regions can be narrowed down using precise mapping techniques to find potential genes in charge of trait expression. Gene discovery and validation are further aided by integration with functional genomics and bioinformatics.

Limitations of QTL Mapping

QTL mapping has certain drawbacks despite its many benefits. In populations with low recombination frequency, the resolution of QTL detection may be reduced, making it challenging to identify specific genes. Variability in QTL detection can result from environmental influences on phenotypic expression. The technique is labour-intensive and time-consuming due to the need for precise phenotyping and large population sizes. Furthermore, data analysis and interpretation may be complicated by interactions between QTLs (epistasis) and between QTLs and the environment. To overcome these obstacles and increase accuracy and dependability, sophisticated statistical models and integrated approaches are required.

Conclusion

By permitting accurate selection of desirable traits and offering a deeper understanding of the genetic basis of complex traits, QTL mapping has transformed crop improvement. It acts as a link between traditional breeding and contemporary molecular genetics, enabling breeders to make well-informed choices and hasten the creation of better crop varieties. QTL mapping is anticipated to become even more important in the future due to continuous developments in genomics, phenotyping, and data analysis. In the face of growing population and climate concerns, its use in the development of high-yielding, stress-tolerant, and nutritionally fortified crops directly contributes to sustainable agriculture and global food security.

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Blending Tradition with Technology: Integrating Indigenous Knowledge and Genomic Tools for Sustainable Crop Improvement

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Shruti Chhetri[1]

[1]M.Sc. Genetics and Plant Breeding Research Scholar, School of Agriculture, Dev Bhoomi Uttarakhand University, Dehradun-248007.

Introduction

New plant breeding technologies (NPBTs), including genetically modified organisms (GMOs) and gene-edited crops, hold significant potential for advancing sustainable agriculture and enhancing food security. These technologies could be transformative by increasing crop yields, reducing the use of chemical fertilizers and pesticides, improving crop resilience to climate stress, minimizing postharvest losses, and producing more nutritious foods. Various gene-editing methods exist, and gene-edited crops with simple point mutations can exhibit new desirable traits. The role of plant genetics remains vital to global food security, peace, and prosperity in the years ahead. The survival of millions depends on how effectively crop genetic improvements can respond to the challenges posed by population growth, climate change, and the depletion of environmental resources.

Historical Background of Plant Breeding

The history of plant breeding dates back to the early days of agriculture, when farmers started choosing plants with desirable characteristics, such increased yields or improved disease resistance. Even though it was simple, this selecting method served as the basis for later systematic breeding techniques. Gregor Mendel's groundbreaking work in genetics had a significant impact on the development of classical breeding techniques in the late 19th and early 20th centuries. Breeders were able to comprehend and forecast the results of their crosses thanks to Mendel's principles of heredity, which laid the foundation for more focused breeding initiatives. A number of technological developments, including as the development of hybridization methods and the identification of genetic markers, made it possible to select and combine features more precisely during the 20th century. These developments improved the accuracy and efficiency of plant breeding, laying the groundwork for the sophisticated genomic and bioinformatics techniques used today. Modern plant breeding has gotten even more advanced with the incorporation of data-driven technologies, including techniques like genome editing, phenotyping platforms, and AI-driven predictive analytics.

Contribution of Plant Genetic Resources to Sustainable Agricultural Practices

The foundation of agriculture in plant genetic resources, which positively and uniquely contribute to the creation of new cultivars as well as the reorganization of existing ones. Sustainable agriculture relies on genotypes that are more resilient to biotic and abiotic stresses. Genes for these characteristics are frequently found in land races and wild species. There are 326 wild crop relatives in India, according to studies on the genetic diversity of these relatives. Genetic diversity, endangered plant species, species diversity and ecosystem stability, global floristic diversity in food plants, genetic resources in India, wild collections of major crops, and plant genetic resources in relation to crop breeding are among the information included in this paper that is necessary to create a breeding plan for sustainable agriculture. focus on and preservation of plant genetic resources, including newly discovered plant genetic resources. Up till April 2006, there were 320,728 accessions overall for various Cereals, millets and forages, pseudocereals, grain legumes, oilseeds, fiber crops, fruits, vegetables, aromatic and medicinal plants, species, condiments, and agroforestry replicate samples in a safe manner. These accessions may be used in the future to create genotypes that can withstand biotic and abiotic stressors. They were kept for long-term storage in the National Gene Bank.

The Role of Genetics and Plant Breeding for Crop Improvement: Current Progress and Future Prospects

In order to ensure sustainable food supply, develop crops, and solve global issues like population increase and climate change, genetics and plant breeding are essential. It talks about how genetic markers, quantitative trait loci (QTL) mapping, and the new science of genomic selection might help choose desired features for plant breeding initiatives. Conventional breeding techniques, hybridization, and to improve agricultural performance, the use of sophisticated molecular breeding technologies is investigated. Furthermore, the possibility of using genome editing tools like CRISPR-Cas9 to speed up breeding and make precise changes to plant genomes is explored. Important aspects of crop development are also covered in the paper, including combining socioeconomic and environmental factors, improving resilience to biotic and abiotic stresses, and striking a balance between yield improvement and agronomic features. The preservation of germplasm and its use in future breeding projects are highlighted. Overall, the analysis emphasizes the

critical role that genetics and plant breeding play in improving crops and emphasizes the necessity of continued research and innovation to meet future problems.

Traditional Plant Breeding Techniques

1. Selection: In this procedure, plants with desired characteristics—like increased production, resistance to disease, or enhanced quality—are chosen and used as parents for the following generation. There are two types of selection: pure line selection, which selects a single plant, and mass selection, which selects a group of plants.
2. Cross-breeding: This method entails purposefully mating two distinct plant varieties in order to combine their best features in the progeny. Breeders seek to create a new generation by carefully choosing parent plants with complementing traits of plants that exhibit the best traits from both parents.

3. Pedigree Breeding: This method keeps track of how qualities are passed down through several generations. Breeders can choose individuals who consistently display the most desired qualities, ensuring the production of new cultivars with improved traits, by meticulously recording the parentage and performance of each plant generation.

4. Procedures for Hybridization and Selection: A crucial method in plant breeding is hybridization, which is the process of crossing two genetically distinct parent plants to create offspring with a variety of desired characteristics. Breeders can create a single plant variety by combining traits like high yield and disease resistance from various cultivars. Selection procedures are used to find and multiply the best progeny after hybridization. This entails assessing the progeny for the required characteristics and choosing those that fulfill the goals of the breeding program. In order to create new plant varieties with improved agricultural performance, hybridization and selection are essential.

Modern Plant Breeding Techniques

In order to create superior crop varieties with increased yield, greater quality, and resistance to pests, diseases, and environmental challenges, modern plant breeding techniques are sophisticated approaches. These methods use technologies from genetics and biotechnology to go beyond conventional selection and hybridization.

1. Marker-Assisted Selection (MAS) selects plants with specific characteristics using DNA markers. Quicker and more accurate than traditional breeding. Frequently applied to quality attributes and disease resistance. Choosing rice types that are resistant to bacterial blight is one example.

2. GS (Genomic Selection) predicts plant performance using whole-genome data. Involves big datasets and statistical models. Aids in quickening the breeding cycle.

3. Transgenic technology, or genetic engineering involves introducing particular genes into the genome of a plant. Produces crops that have been genetically modified (GM). For example: Bt cotton: insect pest resistance Vitamin A-enriched golden rice.

4. Editing Genomes DNA can be precisely altered without adding new genes. CRISPR-Cas9 is the most widely used technique. Applications: Resistance to disease, Tolerance for drought, Enhanced nutritional value.

5. Micropropagation and Tissue Culture sterile in vitro cultivation of plant tissues and cells, used to create plants that are disease-free and multiply quickly.

6. Breeding with Mutations employing radiation or chemicals to cause mutations. Produces genetic diversity. The creation of semi-dwarf wheat cultivars is one example.

7. Rapid Breeding controlled conditions (temperature, light) to reduce crop cycles. Allow multiple generations per year.

8. AI and Bioinformatics in Breeding Analyzes genetic data using computer technologies, aids in decision-making and trait prediction.

Conclusion

By creating high-yielding, resource-efficient, and climate-resilient crop varieties, genetics and plant breeding play a critical role in attaining sustainable agriculture. Breeders can increase tolerance to diseases, pests, and environmental challenges like salt and drought by using contemporary techniques like genome editing and marker-assisted selection. By lowering reliance on chemical inputs like pesticides and fertilizers, these developments lessen their negative effects on the environment and support ecological balance. Better crop types also help ensure food security, increase nutritional quality, and make effective use of water and land resources. In conclusion, creating a resilient, productive, and sustainable agricultural system that can satisfy the demands of both the current and future generations require combining cutting-edge breeding methods with genetic principles.

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Rice Intensification System (SRI) and its Advantages: A Review

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Aditya Raj[1]
[1]M.Sc. Agronomy Research Scholar, School of Agriculture, Dev Bhoomi Uttarakhand University, Dehradun-248007.

Introduction

More over half of the world's population relies on rice as a staple diet, particularly in nations like India. Traditional rice-growing techniques are becoming less sustainable due to growing strain on land, water resources, and the environment. A novel and environmentally beneficial technique that increases rice yield while preserving resources is the System of Rice Intensification (SRI).It prioritises enhancing the rice plant's growing circumstances over relying extensively on external inputs. It improves rice productivity by modifying traditional planting, watering, and soil management procedures.

What is SRI?

A collection of agronomic techniques known as the System of Rice Intensification (SRI) was created to improve rice productivity by altering how plants, soil, water, and nutrients are managed. It is not a new variety of rice, but a set of cultivation practices that help rice plants grow stronger and yield more. It was first used in Madagascar and is currently widely used in many areas that grow rice. It focuses on growing healthier plants with stronger root development.

The Key Principles of SRI

Use of young seedlings& Wider spacing: Seedlingare transplanted at a young age (8-12 days), resulting in greater root development, and Plants are spread widely (typically 25 × 25 cm) to minimize competition and encourage healthy growth or only one plant per spot to avoid competition.

Alternate wetting and drying (AWD): Fields are not continuously inundated; instead, irrigation is used intermittently, to prevent persistent flooding and keep soil moist, and improves oxygen supply to roots (based on soil aeration).

Mechanical weeding & Organic manure: It involves using instruments like a cono weeder to eliminate weeds and aerate soil, and use prefer compost and natural fertilizer.

Benefit of SRI

Water Saving & Improved soil health: It saves 30-50% of water because fields are not constantly inundated.It improves the soil health by use of organic inputs and aeration improves soil structure.

Reduced input costs& Environmentally Friendly: Lower production expenses are achieved by using less seed (5-10 kg/ha) and fewer chemical fertilizers and pesticides.It is more sustainable and environmentally friendly because it uses less water and chemicals, and it has deeper roots, which make them more resistant to drought, pests, and diseases.

SRI vs Traditional Method

Feature	Traditional Method	SRI Method
Seedlings	20-30 days old	8-12 days old
Number per hill	3-4	1
Spacing	Close	Wide
Water use	Continuous flooding	Intermittent
Yield	Moderate	Higher

Challenges of SRI

High Labour demand & requirements for competent management: Wider spacing and careful transplanting of young seedlings require more professional labour, particularly in the beginning, andFarmers must adhere to exacting methods (water control, scheduling, and spacing), which can be challenging without the right training.

Complexity of water management& problems with weed control: In contrast to conventional flooded fields, SRI necessitates more difficult to manage controlled irrigation (alternate soaking and drying), and weeds grow more readily in fields that aren't constantly wet, necessitating frequent hand or machine weeding.

Insufficient Knowledge and instruction: Many farmers may be reluctant to embrace new practices because they are not experienced with SRI techniques, and traditional farmers may resist changing old methods.

Significance of SRI: The System of Rice Intensification (SRI) is critical in agriculture since it increases rice production while utilising fewer natural resources. It encourages sustainable farming by conserving water, lowering seed requirements, and minimising the use of artificial the use of artificial fertilizers. SRI enhances soil health by increasing aeration and utilising organic matter, resulting in stronger root systems and healthier plants. It also increases agricultural output, frequently by 20-50%, thereby ensuring food security for a growing population. In addition, SRI lowers production costs while increasing farmer income. It is especially useful in water-scarce areas and those affected by climatic change.

Conclusion

The system of Rice Intensification (SRI) is a novel and environmentally friendly way of rice growing that increases production while using fewer resources. Developed in Madagascar, it emphasises young seedlings, broader spacing, single plant transplanting, and improved water management through alternate wetting and drying. It also promotes the application of organic manure and mechanical weeding to increase soil health and root growth. SRI improves plant vigour, promotes tillering, and can greatly increase yield while conserving water and seeds. Although it involves talent, careful administration, and greater initial effort, the long-term rewards make it extremely useful. Its major strengths of SRI is its ability to reduce water usage and lower input costs, making it especially valuable in regions facing water scarcity and economic constraints. Additionally, it promotes environmentally friendly farming by improving soil fertility and reducing dependence on chemical fertilizers and pesticides.

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Precision Agriculture and its Role in Crop Productivity

Article ID: 73561

Vikash Kumar[1], Sachin Singh[1]
[1]M.Sc. Agronomy Research Scholar, School of Agriculture, Dev Bhoomi Uttarakhand University, Dehradun.

Introduction

Precision Agriculture is a contemporary agriculture strategy that employs cutting-edge technologies to increases crop production efficiency and yield. Crop and soil management entails watching, measuring and responding to fields variability. The primary goal of precision agriculture is to administer the proper number of inputs such as water, fertilizers, and pesticides at the appropriate time and location. this strategy assists farmer in increasing agriculture yields lowering production costs and protecting the environment. With rising food demand and limited natural resources precision agriculture has emerged as an important tool for sustainable farming.

Concept of Precision Agriculture

Precision agriculture, also known as site-specific crop management, concentrates on the careful management of agricultural areas. In traditional farming, inputs are often delivered consistently over the whole field, even if soil fertility, moisture, and crop conditions differ from one region to the next. Precision agriculture detects these variances and enables farmers to manage each area of the field based on its unique requirements. This enhances resource efficiency and promotes crop development.

Technologies Used in Precision Agriculture

Precision agriculture employs a variety of tools to gather and analyse data on crop and soil conditions.

1. Global Positioning Systems (GPS): Farmers may use GPS technology to establish their exact location within the field. It enables accurate field mapping and directs machines during planting, fertilisation, and harvesting.

2. Geographic Information System (GIS): GIS is used to analyse and interpret data gathered in fields. It aids in the creation of maps depicting soil fertility, moisture levels, crop health, and insect infestation.

3. Remote Sensing: Remote sensing is the use of satellites or drones to monitor agricultural conditions from a distance. It aids in detecting plant stress, nutritional shortages, and disease issues at an early stage.

4. Sensors: Sensors put in the soil or field monitor soil moisture, temperature, and nutrient levels. This data enables farmers to make timely decisions concerning irrigation and fertiliser application.

5. Variable rate technology (VRT): Variable rate technology enables farmers to apply fertilisers, insecticides, and water in varied amounts based on the needs of different portions of the field.

Role of Precision Agriculture in Crop Productivity

1. Precision agriculture improves crop output in a variety of ways:
2. Farmers may use fertilisers, water, and pesticides just where they are needed, reducing waste.
3. Modern technology makes it easier to monitor crop health and identify issues early on.
4. Soil mapping helps farmers determine soil fertility and apply fertilisers more effectively.
5. Precision irrigation systems give water based on crop requirements, avoiding over-irrigation.
6. Proper crop management leads to higher growth, yield, and crop quality.

Advantages of Precision Agriculture

1. Increased crop productivity.
2. Effective use of water and fertilisers
3. Reduced manufacturing costs
4. Improved soil health.
5. Reduced environmental pollution

Challenges in Adoption

Despite its benefits, precision agriculture confronts significant hurdles, including expensive initial technology costs, low farmer awareness, and inadequate technical understanding in remote locations. Training programmes and government assistance can help overcome these limitations and encourage the use of precision agriculture.

Conclusion

Precision agriculture is a novel strategy that increases agricultural yield by utilising current techn ology and data-driven decision-making. It promotes long-term agricultural growth by optimising resource use and crop management. As technology advances, precision agriculture will play an increasingly important role in fulfilling rising food demand while safeguarding natural resources.

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Integrated Nutrient Management in Oats (*Avena sativa*)

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Umasri Dudipala[1], Swarna[1], Nidhi Kumari[1]
[1]M.Sc. Agronomy Research Scholar, School of Agriculture, Dev Bhoomi Uttarakhand University, Deharadun-248007.

Summary
Integrated Nutrient Management in oats (Avena sativa) is a sustainable approach to the use of chemical fertilizers, organic manures, green manure and biofertilizers, to maintain soil fertility, improve nutrient-use efficiency, maximize crop productivity and reduce environmental impact. Oats being nutrient-responsive fodder and cereal crops require a study supply of nitrogen (N), phosphorus (P), potassium (K) quickly to meet demand of growing oats. Biofertilizers, such as Azotobacter or Phosphate-solubilizing bacteria, enhance Nitrogen fixation and Nutrient availability naturally. Together, they create a nutrient-rich environment that supports crop growth. INM is essentially about "Feeding the soil to feed the crop ", while Organic sources of FYM and compost @ 10-15 t/ha before sowing. And Chemical fertilizer of nitrogen 60-80 kg/ha (split dose: ½ at sowing, ½ at tillering stage, phosphorus: 40-50 kg/ha at sowing and potassium: 30-40 kg /ha at sowing for Biofertilizers: Azotobacter or phosphate-solubilizing bacteria at sowing enhance nutrient uptake.

Introduction
Integrated Nutrient Management (INM) is a holistic approach to plant nutrition that involves the combined and balanced use of chemical fertilizers, organic manures, crop residues, and biofertilizers to sustain soil fertility and crop productivity over the long term. The concept of INM is based on the principle that no single source of nutrients is capable of meeting crop demand while maintaining soil health, especially under intensive cropping systems.

Importance of INM in Oats
Oats (*Avena sativa L.*) is one of the most important rabi fodder crops, widely cultivated for its high green biomass yield, palatability, and nutritional value for livestock. Due to its rapid vegetative growth and multiple cuttings, oats require a continuous and balanced supply of nutrients, particularly nitrogen. However, sole application of chemical fertilizers is often inefficient and leads to declining soil health and reduced sustainability of production systems

INM plays a crucial role in oat cultivation by addressing these challenges through the integration of multiple nutrient sources. The importance of INM in oats can be understood through the following aspects:

Table: Integrated Nutrient Management Treatments in Oats:

Treatments	Nutrient Combination	Green Fodder yield (t/ha)	Remarks
T1	100%RDF (NPK)	45-50	control
T2	100%RDF+FYM (5 t/ha)	52-58	Improved soil condition
T3	75%RDF+FYM	55-60	Efficient nutrient use
T4	50%RDF+FYM+Azotobacter	60-72	Highest yield & quality
T5	50%RDF+Vermicompost	58-65	High organic effect
T6	25%RDF+FYM+Biofertilizer	48-55	Moderate yield

Sustaining Soil Fertility: Continuous cultivation of oats with high nutrient removal can lead to nutrient depletion and soil degradation. INM helps in replenishing soil nutrients through organic and biological sources, thereby maintaining long-term soil fertility

Improving Nutrient Use Efficiency (NUE): Chemical fertilizers alone often show low efficiency due to losses through leaching, volatilization, and denitrification. The addition of organic manures and biofertilizers improves nutrient retention and availability, leading to higher NUE

Enhancing Crop Growth and Yield: Research studies have shown that integrated application of 50–75% recommended dose of fertilizers (RDF) along with FYM and biofertilizers significantly increases plant height, tiller number, and green fodder yield in oats compared to sole fertilizer use

Improving Fodder Quality: INM enhances the crude protein content, digestibility, and nutrient composition of oat fodder due to better nitrogen availability and balanced nutrition. This is particularly important for improving livestock productivity.

Enhancing Soil Biological Activity: Organic inputs in INM stimulate soil microbial biomass and enzymatic activities, which play a key role in nutrient cycling and availability

Reducing Environmental Pollution: Excessive use of chemical fertilizers leads to nitrate leaching and greenhouse gas emissions. INM reduces these environmental risks by optimizing fertilizer use and incorporating eco-friendly inputs

Conclusion

INTEGRATED NUTRIENT MANAGEMENT (INM) in Oats (*Avena sativa L.*) is an effective and sustainable approach for improving crop productivity, soil fertility, and environmental health. The combined use of organic manures (such as FYM, green manure, compost and vermicompost) inorganic fertilizers, and biofertilizers ensures balanced nutrient supply and enhances nutrient use efficiency. Partial substitution of chemical fertilizers with organic sources (50-70% RDF combined with FYM, vermicompost or biofertilizers like Azotobacter significantly improves fodder yield, quality, and soil properties.

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Plant-Microbe Interactions Unravelling the Molecular Mechanisms

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Dr. Dinesh H. Chaudhary[1], Dr. Jasmee R. Patel[2], Dr. Mulji D. Jehani[3], Dr. Neetu T. M.[4]

[1]Assistant Professor (Plant Pathology), Office of the Director of Research, Navsari Agricultural University, Navsari, Gujarat.

[2]Assistant Professor (Plant Pathology), KKIASR, Ganpat University, Kherva, Mahesana, Gujarat.

[3]Scientist (Plant Protection), Krushi Vigyan Kendra, SDAU, Deesa, Gujarat.

[4]Assistant Professor, Department of Soil Science and Agricultural Chemistry, N. M. College of Agriculture, NAU, Navsari, Gujarat.

Abstract

Plant-microbe interactions are considered one of the most dynamic and highly evolved biological systems responsible for the regulation of plant wellbeing, productivity, and ecological functions. Plant-microbe interactions include both mutualistic associations as well as those that can be considered pathogenic and are mediated by highly sophisticated networks of molecular signalling. Molecular signalling between plants and microorganisms includes numerous biochemical steps, such as signal recognition, transduction, gene expression re-programming and metabolism adjustment. Recent advancements in molecular biology, genomics and systems biology considerably contributed to further knowledge on these issues. The following review considers molecular aspects of plant-microbe interactions with a focus on immune signalling, symbiotic interaction, pathogen strategies and omics technologies.

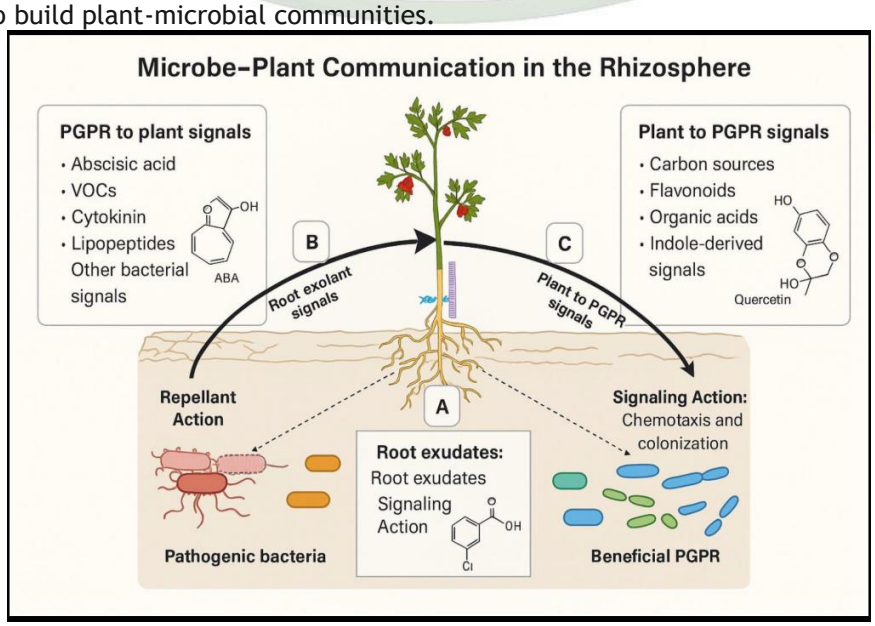
Introduction

Interactions of plants with microbes are an integral part of life on land, as well as agriculture. The living body of a plant is surrounded by a multitude of various microorganisms – from bacteria, fungi, archaea to viruses, especially those located within the rhizosphere, phyllosphere, and endosphere. Microorganisms can have either a positive, neutral, or negative impact on plants' growth and development. On a molecular level, the process of plant-microbe interactions is controlled by complex mechanisms of intercellular signalling, which help the plant organism differentiate good microbes from bad ones.

The rhizosphere, often referred to as “the hotspot of microbial life,” is a very interactive environment where the plant root system releases many chemicals. The release affects both the recruitment of the microbes and their functioning. In response, the microorganisms release signalling molecules, enzymes, and metabolites affecting the physiological state of the plant. Thus, molecular interactions take place (Yang et al., 2024).

Nature and Spectrum of Plant-Microbe Interactions

The relationship between plants and microbes can range anywhere from mutualism to parasitism on a continuum. Mutualism is described as reciprocal benefits, such as increased uptake of nutrients and growth, while pathogenesis refers to the induction of disease and decrease in the health of the plant. Commensalism, which has been less explored but significant, helps to build plant-microbial communities.



Mutualisms like rhizobial symbioses with legumes and plants with mycorrhizae are highly specific and require strict molecular signaling. The mutualism has evolved for millions of years, resulting in highly specific recognition to maximize efficiency of these relationships. On the other hand, pathogens utilize virulence mechanisms to infect and exploit their host.

Molecular Communication in the Rhizosphere

The rhizosphere represents a dynamic interface for molecular interactions between plants and microbes. Plants produce a variety of exudates from their roots in the form of sugars, amino acids, organic acids, phenolics, and secondary metabolites such as flavonoids. These chemicals not only act as nutrients but also act as signals to attract or deter particular groups of microbes.

For example, flavonoids are involved in establishing symbiotic relations with rhizobia through upregulation of nodulation genes. On the other hand, strigolactones secreted by roots of the plant cause the germination and hyphal growth of arbuscular mycorrhizae. These signal molecules are detected by the receptors in the microbes, thereby eliciting chemotactic responses leading to colonization processes. Colonization includes binding to the roots, biofilm production, and multiplication. Biofilms ensure stable association with the plant host. This process of colonization involves coordinated expression of genes in both organisms (Yang et al., 2024).

Molecular Basis of Plant Immunity

Plants possess an innate immune system capable of detecting and responding to microbial invasion. This system operates through two major layers of defence: pattern-triggered immunity (PTI) and effector-triggered immunity (ETI). Pattern-triggered immunity is initiated when plant pattern recognition receptors (PRRs) detect conserved microbial signatures known as pathogen-associated molecular patterns (PAMPs), such as bacterial flagellin or fungal chitin. This recognition activates a cascade of signalling events, including calcium influx, production of reactive oxygen species, activation of mitogen-activated protein kinases, and transcriptional reprogramming of defence genes. These responses collectively strengthen the plant's basal defence mechanisms.

Effector-triggered immunity represents a more specialized and robust defence system. Pathogens deliver effector proteins into plant cells to suppress PTI and facilitate infection. In response, plants have evolved resistance (R) proteins that recognize specific effectors, either directly or indirectly, leading to a rapid and amplified immune response. This often culminates in the hypersensitive response, a localized cell death that restricts pathogen spread (Nadarajah and Rahman, 2021). Plant immune responses are tightly regulated by phytohormones, particularly salicylic acid, jasmonic acid, and ethylene. These hormones interact through complex signalling networks, enabling plants to tailor their defence strategies according to the type of pathogen encountered. Crosstalk among these pathways ensures a balanced allocation of resources between growth and defence.

Molecular Mechanisms of Symbiotic Interactions

Symbiotic interactions represent a highly coordinated form of plant–microbe communication, involving mutual recognition and signalling. In the Rhizobium–legume symbiosis, plant-derived flavonoids activate bacterial nodulation genes, leading to the synthesis of Nod factors. These signalling molecules are recognized by plant receptor-like kinases, initiating a signalling cascade known as the common symbiosis pathway. This results in root hair curling, infection thread formation, and ultimately the development of root nodules where nitrogen fixation occurs.

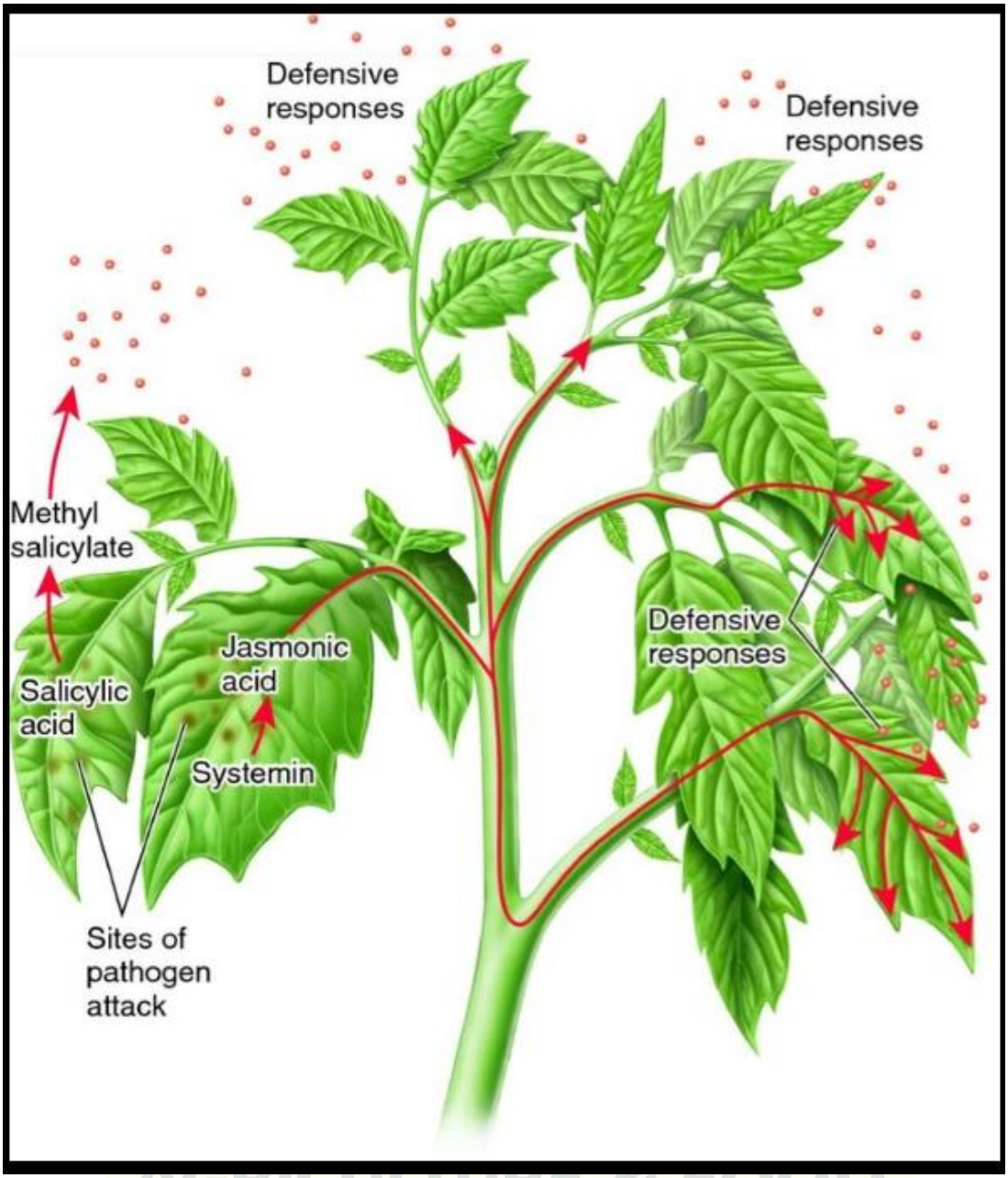
Arbuscular mycorrhizal symbiosis involves the formation of specialized structures called arbuscules within root cortical cells. These structures facilitate nutrient exchange between the plant and the fungus. The molecular mechanisms underlying this interaction involve conserved signalling components shared with rhizobial symbiosis, highlighting the evolutionary conservation of symbiotic pathways (López-Ráez et al., 2025). Endophytic microbes establish themselves within plant tissues without causing disease. These interactions require a delicate balance between microbial colonization and host immune tolerance. Endophytes often modulate plant hormone levels and produce bioactive compounds that enhance plant growth and stress tolerance.

Microbial Strategies in Plant Interaction

Microorganisms have evolved diverse strategies to interact with plants, whether as mutualists or pathogens. Pathogenic microbes produce effector proteins that manipulate host cellular processes, suppress immune responses, and alter plant metabolism to favour infection. These effectors target key components of plant signalling pathways, including transcription factors and hormone signalling networks.

Beneficial microbes, on the other hand, promote plant growth through mechanisms such as nitrogen fixation, phosphate solubilization, and production of phytohormones. They also produce antimicrobial compounds, siderophores, and volatile organic compounds that inhibit pathogen growth and enhance plant defence. Quorum sensing is another important mechanism by which microbes regulate gene expression in response to population density. This allows coordinated

expression of traits such as virulence, biofilm formation, and secondary metabolite production, thereby optimizing interaction outcomes.



Systemic Resistance Mechanisms

Plants can develop enhanced resistance to pathogens through systemic signalling mechanisms. Systemic acquired resistance is typically associated with salicylic acid signalling and is activated following localized pathogen infection. It provides long-lasting protection against a broad spectrum of pathogens. Induced systemic resistance, on the other hand, is triggered by beneficial microbes such as plant growth-promoting rhizobacteria. This form of resistance is mediated primarily by jasmonic acid and ethylene signalling pathways and primes the plant for faster and stronger defence responses upon subsequent pathogen attack (Dolatabadian et al., 2020).

OMICS Approaches and Systems Biology

The advent of high-throughput omics technologies has revolutionized the study of plant–microbe interactions. Genomics and transcriptomics have enabled the identification of genes involved in signalling, defence, and symbiosis. Proteomics has provided insights into protein interactions and post-translational modifications, while metabolomics has revealed the complex chemical exchanges that underpin these interactions.

Metagenomics and microbiome analysis have further expanded our understanding by characterizing the diversity and functional potential of microbial communities associated with plants. Integration of multi-omics data through systems

biology approaches allows for a holistic understanding of PMIs, uncovering novel regulatory networks and interaction mechanisms.

Environmental Influences on Plant-Microbe Interactions

Environmental factors play a critical role in shaping plant–microbe interactions. Soil type, nutrient availability, temperature, and moisture levels influence microbial diversity and activity, as well as plant physiological responses. Agricultural practices such as fertilization, pesticide use, and crop rotation also impact the structure and function of plant-associated microbiomes. Climate change adds another layer of complexity by altering environmental conditions and affecting the distribution and behavior of both plants and microbes. Understanding these influences is essential for developing resilient agricultural systems.

Applications in Sustainable Agriculture

The understanding of mechanisms associated with plant-microbe relationships is important in sustainable agriculture. The utilization of helpful microorganisms as bio-fertilizers and bio-control measures can lead to decreased reliance on chemicals, resulting in increased plant productivity. One promising area includes microbiome manipulation and the design of synthetic communities. In addition, recent developments in genetic engineering, particularly the use of technologies such as CRISPR, can be applied to modify plant-microbe interactions to improve resistance to pathogens and increase efficiencies associated with the uptake of nutrients.

Challenges and Future Perspectives

Despite significant progress, several challenges remain in the field of plant–microbe interactions. The complexity of microbial communities and their interactions with plants under natural conditions is not yet fully understood. Many microbes remain unculturable, limiting functional characterization. Additionally, the performance of microbial inoculants in field conditions is often inconsistent due to environmental variability. Future research should focus on integrating multi-omics approaches, developing predictive models, and exploring synthetic biology tools to design optimized plant–microbe systems. Interdisciplinary approaches combining molecular biology, ecology, and computational sciences will be essential for advancing this field.

Conclusion

The plant-microbe relationship is regulated by extremely complex molecular mechanisms that include signalling pathways, immune responses, and metabolic activities. Such interactions are important in defining the plant's well-being, productivity, and ecological stability. The development of molecular science and omics approaches has shed more light on such mechanisms, leading to innovative ways to practice agriculture sustainably. Further exploration and innovation are necessary to fully exploit the relationship between plants and microbes for increased crop productivity and global food security.

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Emerging Fungal Diseases in Crops: Current Status and Future Directions

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Dr. Dinesh H. Chaudhary[1], Dr. Jasmee R. Patel[2], Dr. Mulji D. Jehani[3], Mr. Lala S. Chaudhary[4]

[1]Assistant Professor (Plant Pathology), Office of the Director of Research, Navsari Agricultural University, Navsari, Gujarat.

[2]Assistant Professor (Plant Pathology), KKIASR, Ganpat University, Kherva, Mahesana, Gujarat.

[3]Scientist (Plant Protection), Krushi Vigyan Kendra, SDAU, Deesa, Gujarat.

[4]Ph. D. Scholar (Entomology), N. M. College of Agriculture, Navsari Agricultural University, Navsari, Gujarat.

Abstract

Recently emerging fungal pathogens have become a key problem in ensuring agricultural sustainability and food security around the world. The increasing occurrence of new diseases in crops, re-emergence of some diseases previously brought under control, and the development of highly virulent isolates pose a significant threat to the productivity of the affected crops. The above phenomena have been attributed to climate change, increased global movement of goods, intensified agricultural activities, and the development of fungicide resistance. Emerging pathogens of fungi are adaptable, highly host-specific, and show complex epidemiology, which makes them difficult to manage. This paper presents a comprehensive review of the latest information about the emergence of fungal pathogens of crops, factors causing their emergence, impacts on major cropping systems, and new technologies for their detection and management.

Introduction

Historically, the impact of fungal infections on agriculture has been considerable, but there has been an exponential rise in their importance in recent years due to new strains of pathogenic fungi along with the loss of current protective strategies. In the global context, diseases have caused considerable yield reduction, where fungal infections contribute significantly (Fisher et al., 2012; Savary et al., 2012). Fungal infection development is a more complicated process than a biological event.

New fungal diseases are distinguished by their spontaneous occurrence in different areas, increase in pathogenicity, and infection of cultivars that were resistant before. Fungal diseases usually result from organisms that had remained inconsequential in the past but have been enabled to flourish in favorable environmental conditions or through alterations in crop cultivation practices. Increasing globalization in agriculture has also contributed to faster transmission of fungal infections around the globe, thus posing threats of epidemics in important food staples (Ristaino et al., 2021).

Concept and Nature of Emerging Fungal Diseases

Emerging fungal diseases encompass newly identified pathogens, re-emerging diseases, and pathogens that have undergone genetic shifts leading to enhanced aggressiveness or host range expansion. Unlike traditional plant diseases, these pathogens often exhibit high genetic plasticity, enabling them to adapt quickly to environmental changes and host defences.

The ability of fungi to produce vast quantities of spores, survive under adverse conditions, and disperse through air, water, and human-mediated activities makes them particularly effective as emerging threats. Additionally, many fungal pathogens exhibit cryptic infection stages, remaining undetected until disease symptoms become severe, thereby complicating early diagnosis and management.

Drivers of Emergence

1. Climate Change and Environmental Variability: Climate change has profoundly influenced the epidemiology of fungal diseases. Rising temperatures, increased humidity, altered rainfall patterns, and extreme weather events create favourable conditions for fungal growth, sporulation, and dissemination. These environmental shifts also alter host physiology, often making plants more susceptible to infections. Changes in seasonal patterns can disrupt the synchrony between host resistance and pathogen activity, leading to unexpected disease outbreaks.

2. Global Trade and Pathogen Dissemination: The globalization of agricultural trade has significantly contributed to the spread of fungal pathogens beyond their native ranges. The movement of infected plant materials, seeds, and soil facilitates the introduction of exotic pathogens into new ecosystems where native crops may lack resistance. This phenomenon has been responsible for several major disease outbreaks in recent history.

3. Agricultural Intensification: Modern agricultural practices, including monoculture, high planting density, and excessive use of agrochemicals, have created environments conducive to disease emergence. Reduced genetic diversity in crops increases vulnerability to pathogen attacks, while intensive farming systems promote rapid pathogen multiplication and evolution.

4. Pathogen Evolution and Genetic Adaptation: Fungal pathogens possess remarkable genetic diversity and adaptability. Mechanisms such as mutation, recombination, and horizontal gene transfer enable them to evolve rapidly and overcome host resistance. The emergence of new virulent races and pathotypes is a direct consequence of these evolutionary processes.

5. Fungicide Resistance: The widespread and often indiscriminate use of fungicides has led to the development of resistant fungal populations. Resistance reduces the effectiveness of chemical control measures and necessitates the development of alternative management strategies.

Major Emerging Fungal Diseases in Crops

Emerging fungal diseases have been reported across a wide range of crops, including cereals, pulses, oilseeds, fruits, and vegetables. In wheat, the emergence of wheat blast caused by *Magnaporthe oryzae* pathotype Triticum has raised global concern due to its rapid spread and devastating yield losses. Similarly, Septoria leaf blotch and tan spot have gained prominence under changing climatic conditions.

In rice, diseases such as bakanae and blast have shown increased incidence and severity, particularly in regions experiencing high humidity and temperature fluctuations. In maize, Fusarium ear rot and associated mycotoxin contamination represent significant threats to both yield and food safety.

Horticultural crops are also increasingly affected by emerging fungal pathogens, including species of *Colletotrichum*, *Alternaria*, and *Sclerotinia*. These pathogens not only reduce yield but also affect post-harvest quality and marketability. Post-harvest fungal diseases are becoming more prominent due to extended storage periods and global supply chains, leading to significant economic losses.

Table 1: Emerging Fungal Diseases in Major Agronomic and Horticultural Crops:

Crop	Disease Name	Causal Organism	Key Symptoms	Regions of Emergence /Concern
Wheat	Wheat blast	*Magnaporthe oryzae* pathotype Triticum	Spike bleaching, shriveled grains, partial head sterility	South America, South Asia (Bangladesh, India)
Wheat	Septoria leaf blotch	*Zymoseptoria tritici*	Necrotic lesions with pycnidia on leaves	Europe, Asia
Rice	Rice blast (resurgence)	*Magnaporthe oryzae*	Diamond-shaped lesions, neck rot, yield loss	Asia, Africa
Rice	Bakanae disease	*Fusarium fujikuroi*	Elongated seedlings, chlorosis, sterility	Asia (India, Japan)
Maize	Fusarium ear rot	*Fusarium verticillioides*	Kernel rot, mycotoxin contamination	Worldwide
Maize	Tar spot	*Phyllachora maydis*	Black tar-like stromata on leaves	Americas (expanding globally)
Chickpea	Dry root rot	*Rhizoctonia bataticola*	Root rot, sudden wilting	South Asia
Lentil	Ascochyta blight	*Ascochyta lentis*	Leaf spots, stem lesions, pod infection	Asia, Canada
Mustard	Alternaria blight	*Alternaria brassicae*	Dark concentric leaf spots, defoliation	India, Asia
Groundnut	Stem rot	*Sclerotium rolfsii*	Collar rot, white mycelium, plant death	Tropical regions
Soybean	Charcoal rot	*Macrophomina phaseolina*	Stem discoloration, premature senescence	Asia, USA
Tomato	Early blight	*Alternaria solani*	Target-like leaf spots, fruit rot	Worldwide
Tomato	Fusarium wilt (new races)	*Fusarium oxysporum* f. sp. *lycopersici*	Yellowing, vascular browning, wilting	Global
Potato	Late blight (aggressive strains)	*Phytophthora infestans*	Water-soaked lesions, tuber rot	Worldwide
Chili	Anthracnose	*Colletotrichum capsici*	Fruit lesions, sunken spots	Asia
Mango	Anthracnose	*Colletotrichum gloeosporioides*	Black lesions on fruits and leaves	Tropical regions
Banana	Panama disease (TR4)	*Fusarium oxysporum* f. sp. *cubense* TR4	Yellowing, vascular wilt, plant death	Asia, Africa

Apple	Apple scab (emerging races)	*Venturia inaequalis*	Leaf spots, fruit blemishes	Europe, North America
Citrus	Citrus black spot	*Phyllosticta citricarpa*	Black lesions on fruits	Africa, South America
Tea	Blister blight	*Exobasidium vexans*	Blister-like lesions on leaves	India, Sri Lanka
Coffee	Coffee leaf rust (new virulent strains)	*Hemileia vastatrix*	Orange pustules, defoliation	Latin America, Africa
Turmeric	Leaf blotch	*Taphrina maculans*	Brown spots on leaves	India
Ginger	Soft rot (fungal complex)	*Pythium spp.*	Rhizome rot, wilting	Tropical regions
Stored grains	Aflatoxin contamination	*Aspergillus flavus*	Toxin production, grain spoilage	Tropical & subtropical regions
Fruits (general)	Blue mold	*Penicillium expansum*	Soft rot, toxin contamination	Storage systems worldwide

Epidemiology and Disease Dynamics

The epidemiology of emerging fungal diseases is highly complex and influenced by interactions among host plants, pathogens, and environmental conditions. Many fungal diseases exhibit polycyclic infection patterns, allowing multiple infection cycles within a single growing season. This results in rapid disease escalation under favourable conditions.

Airborne dispersal of spores enables pathogens to spread over long distances, while soil-borne pathogens can persist for extended periods, acting as reservoirs of infection. Latent infections further complicate disease management, as infected plants may appear healthy until environmental conditions trigger symptom expression. Recent studies have highlighted the importance of co-infections, where multiple pathogens interact within the same host, influencing disease severity and progression. These interactions can lead to synergistic effects, making disease outbreaks more severe and difficult to control.

Impact on Crop Production and Food Security

Emerging fungal diseases have profound implications for agricultural productivity, food security, and economic stability. Yield losses caused by fungal pathogens can be substantial, often exceeding 30–50% under severe conditions (Savary et al., 2012). These losses are particularly critical in staple crops such as wheat, rice, and maize, which form the backbone of global food systems.

In addition to yield reduction, fungal pathogens can produce mycotoxins that contaminate food and feed, posing serious health risks to humans and livestock. The economic burden of managing fungal diseases, including the cost of fungicides and crop losses, is significant and disproportionately affects smallholder farmers in developing countries.

Advances in Detection and Diagnosis

Recent advances in molecular biology and biotechnology have revolutionized the detection and diagnosis of fungal diseases. Techniques such as polymerase chain reaction, quantitative PCR, and next-generation sequencing allow for rapid and accurate identification of pathogens, even at early stages of infection. The integration of remote sensing technologies, including hyperspectral imaging and drone-based monitoring, has enabled large-scale disease surveillance. Artificial intelligence and machine learning algorithms are increasingly being used to analyse disease patterns and predict outbreaks, providing valuable tools for precision agriculture.

Management Strategies

The management of emerging fungal diseases requires a holistic and integrated approach. Cultural practices such as crop rotation, use of resistant varieties, and field sanitation play a crucial role in reducing disease incidence. However, the effectiveness of resistant varieties is often short-lived due to the rapid evolution of pathogens.

Chemical control remains an important component of disease management, but its sustainability is threatened by the development of fungicide resistance and environmental concerns. Biological control agents, particularly species of *Trichoderma* and *Bacillus*, offer promising alternatives by enhancing plant defense mechanisms and suppressing pathogen growth. Integrated disease management strategies that combine cultural, biological, and chemical approaches are considered the most effective means of controlling emerging fungal diseases. Recent developments in nanotechnology have introduced novel tools for targeted delivery of fungicides and improved disease control with reduced environmental impact.

Challenges in Managing Emerging Fungal Diseases

Despite significant advancements, several challenges hinder the effective management of emerging fungal diseases. The rapid evolution of pathogens often outpaces the development of resistant cultivars and new fungicides. Early detection remains difficult, particularly for pathogens with latent infection stages. Climate variability adds another layer of complexity, making disease prediction and management more challenging. Additionally, the lack of awareness and limited access to advanced technologies among farmers, especially in developing countries, restricts the adoption of modern disease management practices.

Future Directions

Future research on emerging fungal diseases should focus on developing durable resistance in crops through advanced breeding techniques and biotechnological approaches. The integration of omics technologies, including genomics, transcriptomics, and metabolomics, can provide deeper insights into host-pathogen interactions and facilitate the development of targeted interventions. The application of artificial intelligence and big data analytics in agriculture holds great promise for improving disease prediction, monitoring, and management. Strengthening global surveillance systems and fostering international collaboration are essential for early detection and rapid response to emerging threats. Sustainable disease management strategies that minimize environmental impact and reduce reliance on chemical inputs should be prioritized. This includes the promotion of biological control agents, organic farming practices, and eco-friendly technologies.

Conclusion

Emerging fungal diseases represent a growing and complex challenge to global agriculture. Their dynamic nature, driven by environmental changes and pathogen evolution, necessitates a comprehensive and multidisciplinary approach to management. Advances in science and technology provide valuable tools for addressing these challenges, but their successful implementation requires coordinated efforts at local, national, and global levels. Ensuring food security in the face of emerging fungal threats will depend on the development of resilient agricultural systems that integrate innovation, sustainability, and effective disease management strategies.

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CRISPR-Cas9 Gene Editing for Disease Resistance in Plants

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Dr. Dinesh H. Chaudhary[1], Dr. Jasmee R. Patel[2], Dr. Mulji D. Jehani[3], Dr. Manjula G. Chaudhari[4]

[1]Assistant Professor (Plant Pathology), Office of the Director of Research, Navsari Agricultural University, Navsari, Gujarat.

[2]Assistant Professor (Plant Pathology), KKIASR, Ganpat University, Kherva, Mahesana, Gujarat.

[3]Scientist (Plant Protection), Krushi Vigyan Kendra, SDAU, Deesa, Gujarat.

[4]Assistant Professor (Biochemistry), Department of Soil Science and Agricultural Chemistry, N. M. College of Agriculture, Navsari Agricultural University, Navsari, Gujarat.

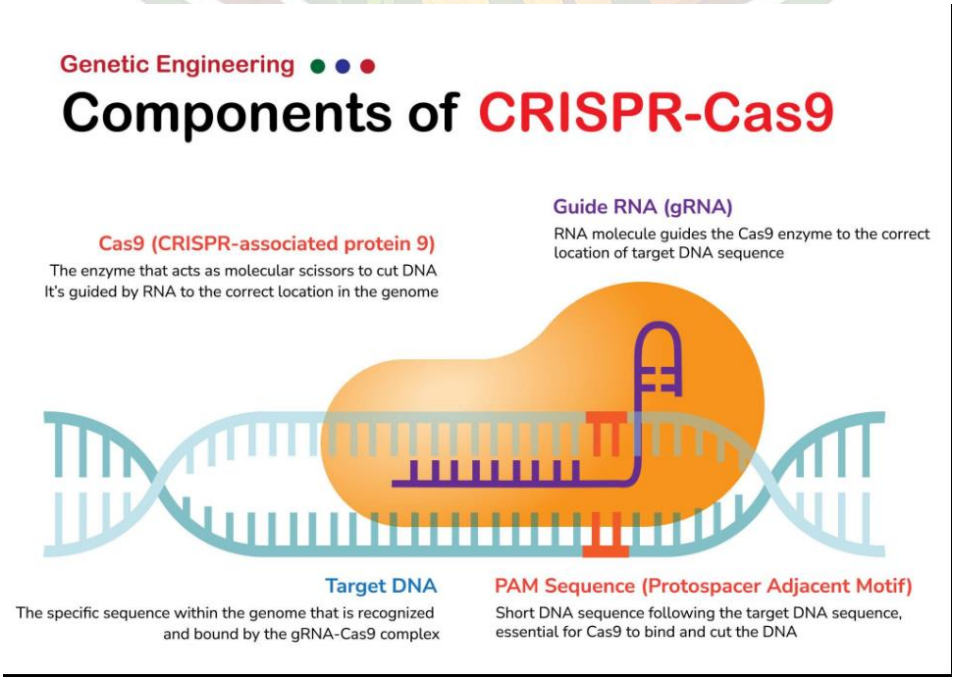
Abstract

The CRISPR-Cas9 system of gene editing has been introduced as an advanced method in plant biotechnology that can modify plants in an efficient manner. This technique is capable of providing opportunities to generate disease-resistant plants through genetic manipulation of immune responses, pathogen interaction, and plant susceptibility genes. In light of growing food demands around the world and the constraints associated with traditional breeding practices, CRISPR-Cas9 appears to be an effective strategy for enhancing resistance to a broad range of pathogens in plants, such as viruses, bacteria, fungi, and oomycetes. This review highlights the fundamentals of the CRISPR-Cas9 system, its use in creating disease resistance in plants, techniques utilized, accomplishments in major crops, difficulties faced, regulatory issues, and future implications.

Introduction

Plant diseases represent some of the major limitations to agricultural production worldwide. They lead to major yield reductions and pose a threat to food security, especially in developing nations. The rising trend in the emergence and resurgence of plant pathogens due to climatic changes and globalization has only increased the demand for sustainable methods to combat plant diseases. Traditional breeding programs, although effective in many instances, are often time-consuming and restricted by the presence of resistant alleles in the gene pool. Transgenic technology, on the other hand, has opened up novel possibilities, but legal and social barriers have hindered its extensive utilization.

In this context, the CRISPR-Cas9 genome editing system has revolutionized plant biotechnology by enabling precise and targeted modifications in plant genomes. Derived from the adaptive immune system of bacteria, CRISPR-Cas9 allows scientists to introduce site-specific changes in DNA sequences, thereby facilitating functional genomics studies and crop improvement. Its simplicity, versatility, and cost-effectiveness have made it a preferred tool over earlier genome editing technologies. The application of CRISPR-Cas9 in developing disease-resistant crops has gained considerable attention, as it provides a sustainable and environmentally friendly alternative to chemical disease control (Borrelli et al., 2018; Tyagi et al., 2020).



Mechanism of CRISPR-CAS9 System

The CRISPR-Cas9 system operates through a highly specific RNA-guided mechanism that enables targeted DNA cleavage. It consists of two essential components: the Cas9 nuclease and a single guide RNA, which directs the nuclease to the target DNA sequence through complementary base pairing. The recognition of a protospacer adjacent motif adjacent to the target site is crucial for Cas9 binding and cleavage. Once bound, Cas9 introduces a double-strand break in the DNA, which is subsequently repaired by the plant's endogenous repair machinery.

Two major repair pathways govern the outcome of CRISPR-mediated editing. Non-homologous end joining is an error-prone process that often results in insertions or deletions, leading to gene knockout or loss of function. In contrast, homology-directed repair enables precise modification by using a donor template, allowing for targeted gene insertion or replacement. Although homology-directed repair is less efficient in plants compared to non-homologous end joining, recent advances have improved its applicability.

The ability to precisely edit genes involved in plant immunity makes CRISPR-Cas9 a powerful tool for developing disease-resistant crops. By targeting specific loci associated with susceptibility or defence responses, researchers can effectively manipulate plant-pathogen interactions at the molecular level (Das et al., 2023).

Strategies for Engineering Disease Resistance Using CRISPR-CAS9

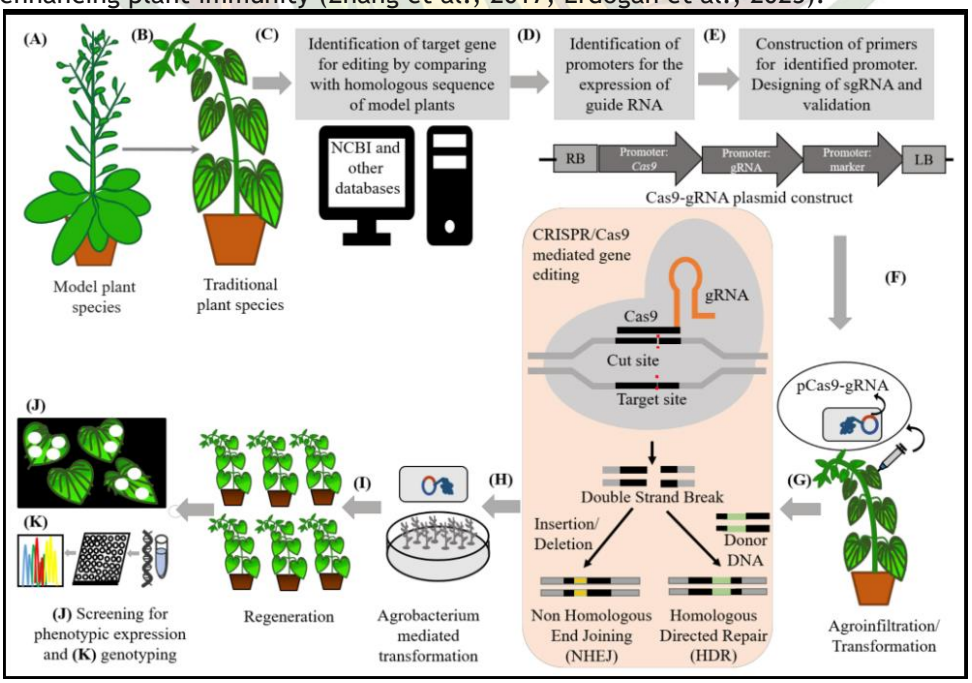
One of the most widely adopted strategies for enhancing disease resistance involves the disruption of susceptibility genes. These genes are exploited by pathogens to establish infection, and their inactivation often leads to enhanced resistance. For instance, the modification of MLO genes has been shown to confer durable resistance against powdery mildew in several crops. This approach is particularly advantageous because it often results in broad-spectrum and long-lasting resistance.

Another important strategy focuses on the modification or enhancement of resistance genes. Resistance genes encode proteins that recognize pathogen effectors and activate defence signalling pathways. CRISPR-Cas9 enables precise editing of these genes to improve their recognition capacity or to create novel resistance traits. Additionally, synthetic resistance genes can be designed to target specific pathogens, thereby expanding the scope of disease resistance.

CRISPR-Cas9 has also been employed to engineer resistance against viral pathogens by directly targeting viral genomes or by modifying host factors required for viral replication. This approach has shown promising results in crops affected by DNA and RNA viruses, offering a potential solution to some of the most challenging plant diseases.

Another significant advancement is multiplex genome editing, which allows the simultaneous targeting of multiple genes. This strategy is particularly useful for developing resistance against complex diseases involving multiple genetic factors. By editing several susceptibility or resistance genes at once, it is possible to achieve enhanced and durable resistance.

Promoter editing represents another innovative approach, wherein regulatory regions of genes are modified to alter their expression patterns. By fine-tuning the expression of defence-related genes, plants can be engineered to respond more effectively to pathogen attacks. This strategy mimics natural resistance mechanisms and provides a subtle yet effective means of enhancing plant immunity (Zhang et al., 2017; Erdoğan et al., 2023).



Applications in Major Crops

The application of CRISPR-Cas9 technology in major crops has demonstrated its immense potential in improving disease resistance. In rice, editing of susceptibility genes such as OsSWEET has conferred resistance to bacterial blight, one of the most devastating diseases affecting this crop. Similarly, modifications in genes associated with blast resistance have enhanced the plant's ability to withstand fungal infections.

In wheat, CRISPR-mediated knockout of TaMLO genes has resulted in resistance to powdery mildew, while editing of other defence-related genes has improved overall immunity. Tomato has also benefited from CRISPR-based interventions, with the deletion of SlMlo1 providing resistance to powdery mildew and other pathogens.

In potato, CRISPR-Cas9 has been used to develop resistance against late blight, a disease caused by an oomycete pathogen that leads to significant yield losses. Similarly, in grapevine, editing of transcription factors involved in defense signalling has enhanced resistance to fungal diseases. These examples highlight the versatility of CRISPR-Cas9 in addressing diverse plant diseases across different crop species, thereby contributing to sustainable agricultural practices (Borrelli et al., 2018; Das et al., 2023).

Advantages of CRISPR-CAS9 in Plant Disease Resistance

CRISPR-Cas9 offers several advantages over traditional breeding and earlier genome editing technologies. Its high precision allows for targeted modifications without affecting unrelated genomic regions. The technology is also relatively simple and cost-effective, making it accessible to a wide range of researchers. The ability to perform multiplex editing enables the development of crops with multiple desirable traits, including resistance to various pathogens.

Another significant advantage is the potential to produce non-transgenic genome-edited crops. Since CRISPR-Cas9 can introduce mutations without incorporating foreign DNA, the resulting plants may not be classified as genetically modified organisms in certain regulatory frameworks. This could facilitate their acceptance and commercialization.

Furthermore, CRISPR-based disease resistance reduces the reliance on chemical pesticides, thereby minimizing environmental pollution and promoting sustainable agriculture. The rapid development of resistant varieties also helps in responding to emerging pathogen threats in a timely manner (Tyagi et al., 2020).

Challenges and Limitations

Despite its numerous advantages, the application of CRISPR-Cas9 in plant disease resistance is not without challenges. One of the primary concerns is the occurrence of off-target effects, which may lead to unintended genetic modifications. Although advancements in guide RNA design and high-fidelity Cas9 variants have reduced this risk, it remains an area of active research.

The efficient delivery of CRISPR components into plant cells is another major challenge. Various methods, including Agrobacterium-mediated transformation and particle bombardment, have been employed, but each has its limitations in terms of efficiency and applicability across different species. Regulatory frameworks governing genome-edited crops vary across countries, creating uncertainties for researchers and stakeholders. While some countries have adopted relatively lenient regulations, others have stringent policies that may hinder the commercialization of CRISPR-edited crops.

Another concern is the potential for pathogens to evolve and overcome resistance mechanisms. Continuous monitoring and the development of integrated disease management strategies are essential to ensure the long-term effectiveness of CRISPR-based resistance. Ethical considerations and public perception also play a crucial role in the adoption of genome editing technologies. Transparent communication and public engagement are necessary to build trust and acceptance.

Recent Advances and Innovations

Recent advancements in CRISPR technology have significantly enhanced its applicability in plant disease resistance. The development of CRISPR variants such as Cas12 and Cas13 has expanded the range of targetable sequences and enabled RNA targeting. Base editing and prime editing technologies allow precise nucleotide changes without introducing double-strand breaks, thereby reducing the risk of unintended mutations.

DNA-free genome editing approaches, which involve the direct delivery of CRISPR components as ribonucleoprotein complexes, have gained attention as they eliminate the integration of foreign DNA. This approach not only improves safety but also simplifies regulatory approval.

Improvements in guide RNA design and the development of high-fidelity Cas9 variants have enhanced editing specificity and efficiency. These innovations are paving the way for more precise and reliable genome editing applications in agriculture (Erdoğan et al., 2023).

Future Prospects

The future of CRISPR-Cas9 in plant disease resistance lies in its integration with other advanced technologies such as genomics, transcriptomics, proteomics, and artificial intelligence. These approaches can provide deeper insights into plant-pathogen interactions and identify novel targets for genome editing.

The development of climate-resilient and disease-resistant crops will be crucial in addressing the challenges posed by climate change and population growth. CRISPR-Cas9 has the potential to accelerate breeding programs and contribute to sustainable agricultural systems. Efforts should also focus on improving delivery methods, minimizing off-target effects, and developing standardized regulatory frameworks. Collaboration between researchers, policymakers, and industry stakeholders will be essential to harness the full potential of CRISPR technology.

Conclusion

CRISPR-Cas9 gene editing represents a ground-breaking advancement in plant biotechnology, offering a powerful and versatile tool for developing disease-resistant crops. Its ability to precisely manipulate genes involved in plant immunity provides a sustainable alternative to conventional breeding and chemical control methods. While challenges remain, ongoing research and technological advancements are expected to overcome these limitations. The adoption of CRISPR-Cas9 in agriculture has the potential to enhance crop productivity, reduce environmental impact, and ensure global food security.

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Automated Weed Detection Using Drones UAV'S

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Meeta Kumari[1], Satish Kumar Pandey[2], Dr. R. P. Manjhi[3], Rajani Kiran Lakra[4]

[1]Ph.D. Scholar, Department of Agronomy, Birsa Agricultural University, Ranchi, Jharkhand.
[2]Ph.D. Scholar, Department of Agronomy, Birsa Agricultural University, Ranchi, Jharkhand.
[3]Associate Professor cum Senior Scientist, Department of Agronomy, Birsa Agricultural University, Ranchi, Jharkhand.
[4]Junior Scientist cum Assistant Professor, Department of Agronomy, Birsa Agricultural University, Ranchi, Jharkhand.

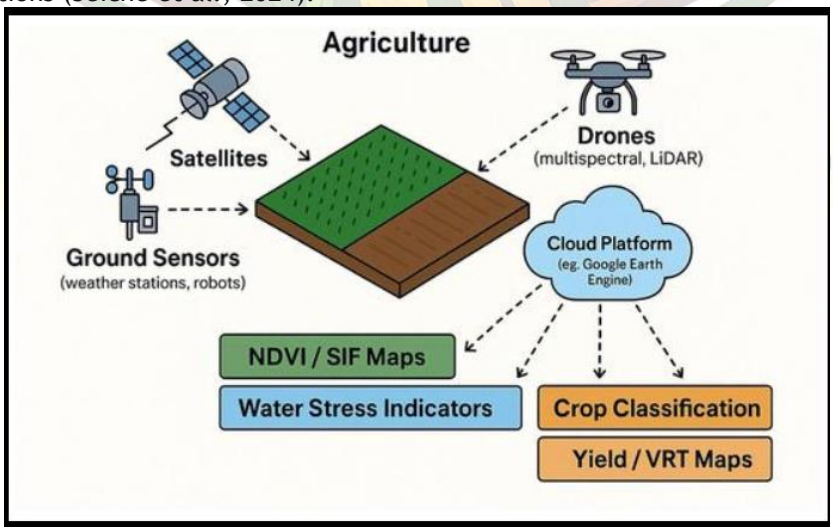
Abstract

Weeds remain one of the most persistent constraints to agricultural productivity, leading to significant yield losses and increased input costs. Conventional weed management strategies are often labor-intensive, inefficient, and environmentally unsustainable due to indiscriminate herbicide use. In recent years, unmanned aerial vehicles (UAVs), commonly referred to as drones, have emerged as a transformative tool in precision agriculture. UAV-based automated weed detection integrates advanced imaging systems, remote sensing, and artificial intelligence to enable real-time monitoring and site-specific weed management. This review presents a detailed and comprehensive account of UAV-assisted weed detection, covering sensor technologies, image processing techniques, machine learning and deep learning approaches, operational frameworks, advantages, constraints, and future prospects. The integration of UAVs with intelligent decision-making systems offers a promising pathway toward sustainable and efficient weed management in modern agriculture.

Introduction

Weeds compete aggressively with cultivated crops for essential resources such as nutrients, water, light, and space, thereby significantly reducing crop yield and quality. It has been estimated that weeds alone account for substantial yield losses across major cropping systems globally. Traditional weed control methods, including manual weeding and blanket herbicide application, are increasingly becoming unsustainable due to rising labour costs, herbicide resistance, and environmental concerns.

Precision agriculture has introduced innovative approaches that aim to optimize resource use and minimize environmental impact. Within this framework, UAV technology has gained considerable attention due to its ability to provide high-resolution spatial and temporal data. UAV-based weed detection systems enable rapid assessment of weed distribution patterns across agricultural fields, facilitating targeted management strategies. The capability of UAVs to operate at low altitudes allows them to capture detailed imagery, which is essential for distinguishing weeds from crops under varying field conditions (Seiche et al., 2024).



UAV Technology and its Role in Weed Detection

Unmanned aerial vehicles are remotely operated or autonomously controlled flying platforms equipped with advanced sensors and imaging devices. They are broadly categorized into fixed-wing and rotary-wing UAVs. Fixed-wing UAVs are

suitable for large-scale agricultural monitoring due to their longer flight endurance and wider coverage area, whereas rotary-wing UAVs offer superior manoeuvrability and are more suitable for small and fragmented fields.

The application of UAVs in weed detection is based on their ability to capture high-resolution imagery that can be processed using advanced algorithms. These systems significantly reduce the time and labor required for field scouting and enable early detection of weed infestations. Furthermore, UAVs can be deployed repeatedly over the growing season, allowing continuous monitoring of weed dynamics and crop-weed interactions (Velusamy et al., 2022).

Sensor Technologies for UAV-Based Weed Detection

The effectiveness of UAV-based weed detection systems largely depends on the type of sensors used for data acquisition. Different sensor technologies provide complementary information that enhances the accuracy of weed identification. RGB cameras are the most commonly used sensors due to their low cost and ease of operation. They capture images in the visible spectrum and are useful for basic weed detection tasks. However, their performance is often limited by variations in lighting conditions and the visual similarity between crops and weeds.

Multispectral sensors capture data in discrete spectral bands, including near-infrared wavelengths. These sensors enable the calculation of vegetation indices such as the normalized difference vegetation index, which helps differentiate plant species based on their physiological characteristics. Multispectral imaging has been widely used for weed mapping and has shown improved detection accuracy compared to RGB imagery (Che'Ya et al., 2021). Hyperspectral sensors provide a more detailed spectral profile by capturing hundreds of narrow spectral bands. This allows precise discrimination between different plant species, including morphologically similar weeds and crops. Hyperspectral imaging, combined with advanced classification algorithms, has demonstrated high potential for accurate weed identification (Mensah et al., 2024). Thermal sensors and LiDAR systems are also being explored for weed detection. Thermal imaging can detect temperature variations associated with plant stress, while LiDAR provides three-dimensional structural information about plant canopies, which can be useful for identifying weeds based on height and morphology.

Image Processing and Analytical Framework

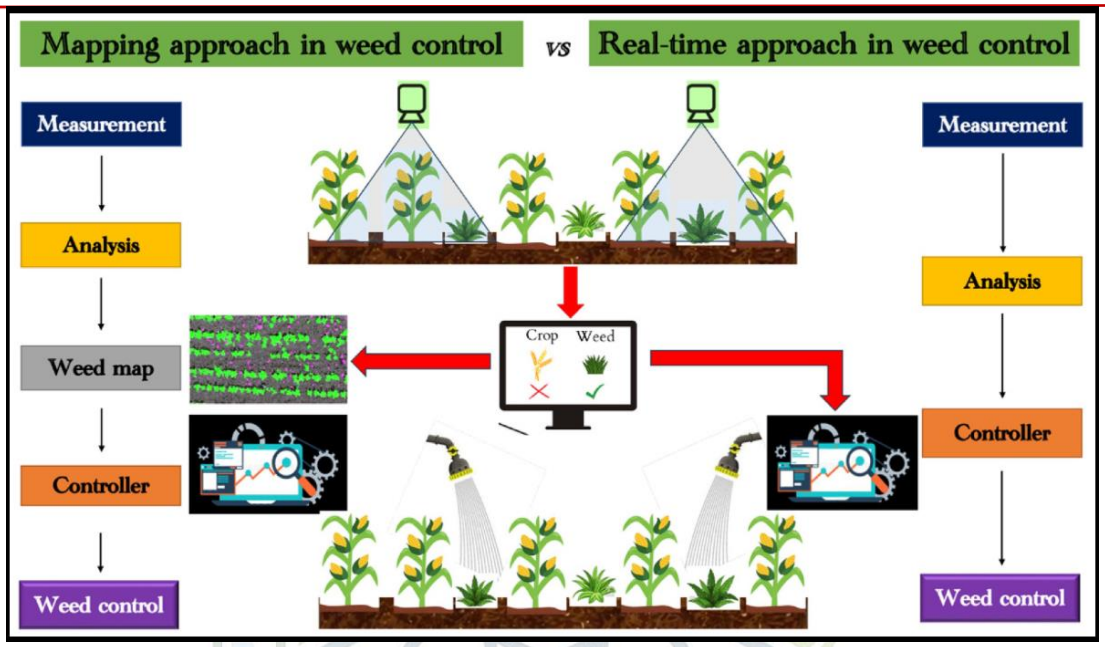
The process of automated weed detection using UAV imagery involves several sequential steps that transform raw data into actionable information. Data acquisition is carried out through carefully planned UAV flights, considering factors such as flight altitude, overlap, and environmental conditions. Pre-processing of images includes radiometric correction to adjust for lighting variations, geometric correction to align images spatially, and mosaicking to create a comprehensive orthomosaic of the field. These steps are crucial for ensuring data consistency and accuracy. Segmentation techniques are then applied to separate vegetation from the background soil. This is followed by feature extraction, where relevant attributes such as colour, texture, shape, and spectral characteristics are derived from the images. These features serve as inputs for classification algorithms that distinguish between crops and weeds.

Machine Learning Approaches in Weed Detection

Machine learning techniques have been extensively used for weed classification in UAV imagery. Traditional algorithms such as support vector machines, random forests, and maximum likelihood classifiers rely on manually extracted features to classify vegetation. These methods have shown moderate success in weed detection tasks; however, their performance is often constrained by the complexity of agricultural environments and the variability in weed morphology. Feature engineering plays a critical role in determining the effectiveness of these models, which can be a time-consuming and expertise-dependent process (Mensah et al., 2024).

Deep Learning-Based Weed Detection

Deep learning has revolutionized the field of automated weed detection by enabling models to learn complex patterns directly from raw data. Convolutional neural networks are particularly effective in image analysis tasks and have been widely adopted for weed detection in UAV imagery. Object detection models such as YOLO and Faster R-CNN enable real-time identification of weeds by detecting and localizing them within images. These models have demonstrated high accuracy and speed, making them suitable for practical applications in precision agriculture (Das et al., 2025). Semantic segmentation models, including U-Net and DeepLab architectures, provide pixel-level classification, allowing precise delineation of weed-infested areas. These models are particularly useful for site-specific herbicide application, where accurate mapping of weed distribution is essential (Shahi et al., 2023). Recent advancements have focused on hybrid approaches that combine object detection and segmentation techniques to improve overall performance. These integrated models offer enhanced accuracy and robustness under diverse field conditions.



Applications in Precision Weed Management

UAV-based weed detection systems have numerous applications in modern agriculture. One of the most significant applications is site-specific weed management, where herbicides are applied only to areas affected by weeds. This approach reduces chemical usage and minimizes environmental impact. Precision spraying using UAVs equipped with spraying mechanisms allows targeted application of herbicides, improving efficiency and reducing costs. Additionally, UAV-based weed mapping enables farmers to monitor weed distribution over time and implement timely control measures. The integration of UAV systems with Internet of Things platforms and decision support systems further enhances their utility by enabling real-time data analysis and automated decision-making.

Advantages of UAV-Based Weed Detection

The adoption of UAV technology in weed management offers several advantages over conventional methods. UAVs provide high-resolution imagery that enables accurate detection of weeds at early growth stages. They significantly reduce the need for manual labour and allow rapid coverage of large agricultural areas. Moreover, UAV-based systems support precision agriculture practices by enabling targeted interventions, which lead to reduced herbicide usage and lower environmental pollution. These systems also facilitate data-driven decision-making, improving overall farm management efficiency (Meesaragandla et al., 2024).

Challenges and Limitations

Despite the promising potential of UAV-based weed detection, several challenges need to be addressed. One of the primary challenges is the difficulty in distinguishing between crops and weeds that have similar visual characteristics. This issue is particularly pronounced in early growth stages. Data availability and annotation also pose significant challenges, as training deep learning models requires large volumes of labelled data. Environmental factors such as lighting conditions, soil variability, and crop growth stages further complicate the detection process. The high computational requirements of deep learning models can limit their deployment in real-time applications. Additionally, regulatory restrictions on drone usage, high initial investment costs, and the need for technical expertise may hinder widespread adoption, especially among smallholder farmers (Vijayakumar et al., 2025).

Future Prospects

The future of automated weed detection using UAVs is highly promising, with ongoing advancements in artificial intelligence, sensor technology, and data analytics. The development of lightweight and cost-effective sensors is expected to make UAV technology more accessible to farmers. Integration with edge computing and cloud-based platforms will enable real-time data processing and decision-making. Autonomous UAV systems with optimized flight planning and swarm intelligence are likely to enhance operational efficiency. Emerging techniques such as reinforcement learning and unsupervised learning are expected to improve the adaptability and robustness of weed detection models. The convergence of UAV technology with robotics and precision spraying systems will pave the way for fully automated weed management solutions.

Conclusion

Automated weed detection using UAVs represents a significant advancement in precision agriculture. By combining high-resolution imaging with advanced machine learning and deep learning techniques, UAV-based systems enable accurate, efficient, and sustainable weed management. Although several challenges remain, continuous technological innovations are expected to overcome these limitations and facilitate large-scale adoption. The integration of UAVs into agricultural practices has the potential to reduce input costs, minimize environmental impact, and enhance crop productivity, thereby contributing to sustainable agricultural development.

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Importance, Scientific Cultivation & Post Harvest Technology of Kodu Millet

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Meeta Kumari[1], Satish Kumar Pandey[2], Dr. R. P. Manjhi[3], Rajani Kiran Lakra[4]

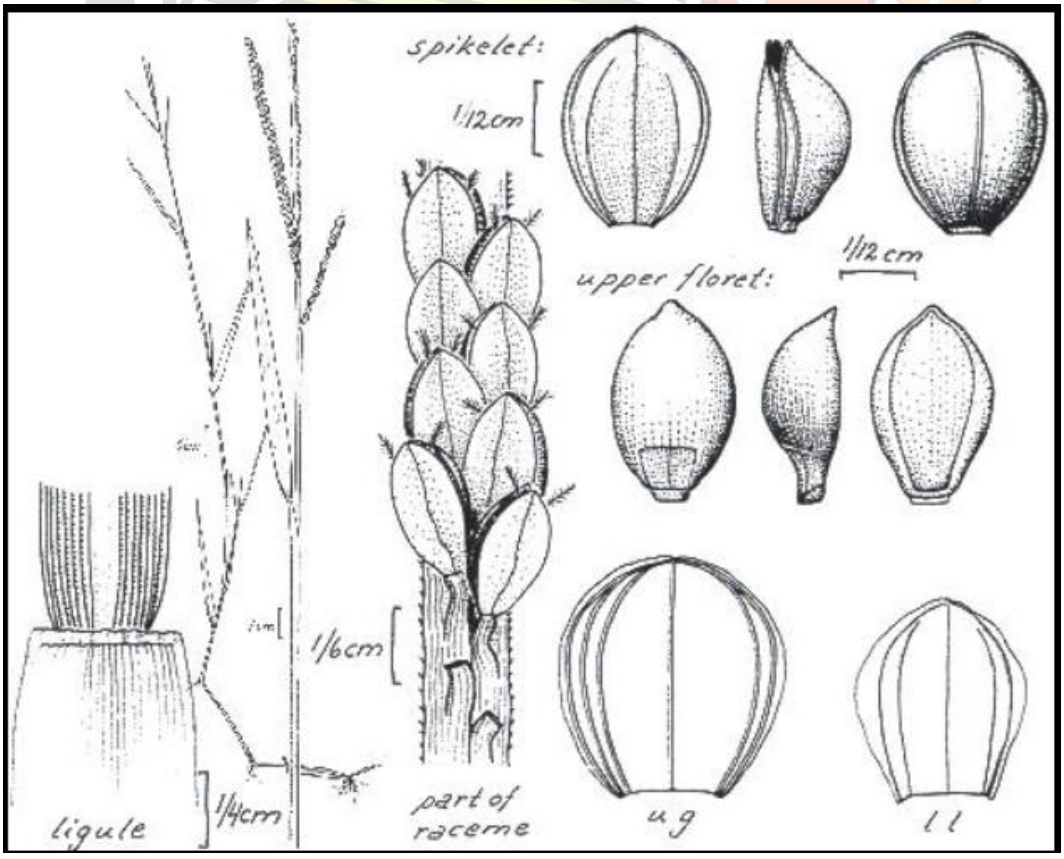
[1]Ph.D. Scholar, Department of Agronomy, Birsa Agricultural University, Ranchi, Jharkhand.
[2]Ph.D. Scholar, Department of Agronomy, Birsa Agricultural University, Ranchi, Jharkhand.
[3]Associate Professor cum Senior Scientist, Department of Agronomy, Birsa Agricultural University, Ranchi, Jharkhand.
[4]Junior Scientist cum Assistant Professor, Department of Agronomy, Birsa Agricultural University, Ranchi, Jharkhand.

Abstract

Kodo millet (*Paspalum scrobiculatum* L.) is a traditional small millet crop with immense potential in ensuring food, nutritional, and livelihood security under changing climatic conditions. It is characterized by its adaptability to marginal environments, low input requirements, and resilience to drought and poor soils. The grain is nutritionally superior, being rich in dietary fiber, essential amino acids, and micronutrients, and has a low glycemic index. Scientific cultivation practices, including appropriate agronomy, nutrient management, and improved varieties, significantly enhance productivity. Post-harvest technologies play a crucial role in preserving grain quality, reducing losses, and enhancing value addition. This review provides a detailed and comprehensive account of the importance, cultivation practices, and post-harvest management of kodo millet, highlighting its role in sustainable agriculture and future food systems.

Introduction

Kodo millet (*Paspalum scrobiculatum* L.) is one of the oldest domesticated cereals belonging to the Poaceae family and has been cultivated for centuries in India, particularly in rainfed and tribal regions. It is predominantly grown in states such as Madhya Pradesh, Chhattisgarh, Tamil Nadu, and parts of Karnataka, where it serves as a staple food for rural populations. In recent years, there has been renewed scientific and policy interest in millets, including kodo millet, due to their climate resilience and nutritional benefits. The crop is well suited to low-input farming systems and marginal lands, making it an important component of sustainable and climate-smart agriculture (Upadhyaya et al., 2014). Its increasing recognition as a “nutri-cereal” has further enhanced its relevance in combating malnutrition and lifestyle diseases.



Importance of Kodo Millet

Kodo millet holds immense importance from nutritional, agronomic, ecological, and socio-economic perspectives. From a nutritional standpoint, it is rich in dietary fiber, which contributes to improved digestion and reduced risk of metabolic disorders. The grain contains appreciable amounts of protein, iron, calcium, and antioxidants, which play a crucial role in preventing micronutrient deficiencies. Its low glycemic index makes it particularly suitable for diabetic patients and individuals with cardiovascular conditions. Furthermore, being gluten-free, it is an ideal dietary option for people suffering from celiac disease (Devi et al., 2011).

Agronomically, kodo millet is highly valued for its adaptability to adverse environmental conditions. It can grow successfully in poor, shallow, and gravelly soils where other cereals fail. The crop requires minimal inputs, including fertilizers and irrigation, and still produces a reasonable yield. Its short duration and ability to fit into diverse cropping systems make it suitable for crop rotation and intercropping systems.

Ecologically, kodo millet contributes significantly to sustainable agriculture. Its low water requirement and tolerance to drought make it a climate-resilient crop. It also plays a role in maintaining soil health due to its compatibility with organic farming practices. Additionally, its cultivation helps conserve agrobiodiversity and supports traditional farming systems.

From a socio-economic perspective, kodo millet supports the livelihoods of small and marginal farmers, particularly in tribal regions. It provides food security, income generation, and employment opportunities in rural areas. With increasing awareness of its health benefits, there is growing market demand, which further enhances its economic potential (Rangaiah et al., 2024).

Scientific Cultivation of Kodo Millet

The scientific cultivation and production technology of kodo millet involve a comprehensive integration of agro-climatic adaptation, soil suitability, and field preparation practices, which collectively determine the success of crop establishment and productivity. A deeper understanding of these foundational components is essential for optimizing yield, particularly under rainfed and marginal farming conditions where kodo millet is predominantly cultivated.

1. Agro-climatic Requirements: Kodo millet is inherently adapted to warm tropical and subtropical climates and is recognized for its exceptional resilience to climatic variability. The crop performs optimally within a temperature range of 25°C to 35°C, which supports efficient physiological processes such as photosynthesis, tillering, and grain development. However, its adaptability extends beyond this range, allowing it to tolerate higher temperatures and intermittent heat stress conditions commonly observed in semi-arid regions. This thermotolerance is attributed to its efficient stomatal regulation and reduced transpiration rates, which enable the plant to conserve water under moisture-deficit conditions.

Rainfall plays a crucial role in determining crop establishment and yield. Kodo millet requires an annual rainfall of approximately 500–900 mm, but its deep-rooting system allows it to utilize residual soil moisture efficiently, making it highly suitable for rainfed agriculture. The crop can withstand prolonged dry spells during vegetative growth, although moisture availability during reproductive stages, particularly flowering and grain filling, is critical for achieving higher yields. Its ability to escape drought through early maturity further enhances its suitability for regions with erratic rainfall patterns.

Another important aspect of its agro-climatic adaptability is its tolerance to low humidity and high solar radiation, conditions under which many other cereals fail to perform. This makes kodo millet particularly valuable in upland ecosystems and dryland agro-ecologies. The crop also exhibits a degree of photoperiod insensitivity, allowing it to be cultivated across a wide range of latitudes and seasons. Such ecological plasticity positions kodo millet as a key crop in climate-resilient agricultural systems (Goutam et al., 2024).

2. Soil Requirements and Field Selection: Kodo millet is highly versatile in terms of soil adaptability, which is one of its defining agronomic advantages. It can grow successfully in a variety of soil types, including sandy, loamy, gravelly, and even degraded soils with low organic matter content. However, well-drained soils are essential to prevent waterlogging, as excess moisture can lead to poor root aeration, reduced nutrient uptake, and increased susceptibility to root diseases.

The crop performs best in soils with a slightly acidic to neutral pH range of 5.5 to 7.5. Within this range, nutrient availability is optimized, enabling better plant growth and development. Despite its ability to tolerate low fertility conditions, soil health plays a significant role in determining yield potential. Soils rich in organic matter support better microbial activity, which enhances nutrient cycling and availability. Therefore, the selection of fields with moderate fertility and good structure is desirable for achieving higher productivity.

Field selection should also consider topography and drainage characteristics. Kodo millet is commonly grown in upland and sloping areas where water stagnation is minimal. Such locations not only reduce the risk of waterlogging but also facilitate better root penetration and aeration. In regions prone to soil erosion, contour farming and bunding practices can be adopted to conserve soil and moisture.

Another critical aspect is the previous cropping history of the field. Fields that have been under legumes or fallow conditions are preferred, as they tend to have better soil fertility and reduced weed pressure. Crop rotation involving pulses can further enhance soil nitrogen levels, thereby improving the subsequent kodo millet crop. Thus, careful soil selection and field planning form the foundation of a successful production system (Upadhyaya et al., 2014).



3. Land Preparation: Land preparation is a fundamental step in the production technology of kodo millet, as it directly influences seed germination, root development, and overall crop establishment. The primary objective of land preparation is to create a fine, firm, and weed-free seedbed that ensures uniform seed placement and optimal soil-seed contact.

The process typically begins with a deep ploughing operation, which helps in breaking compacted soil layers and improving soil aeration. This is particularly important in rainfed areas where soil compaction can limit root penetration and reduce water infiltration. Deep ploughing also aids in exposing soil-borne pests and weed seeds to the surface, where they are destroyed by sunlight and predators.

Subsequent harrowing operations are carried out to break soil clods and achieve a fine tilth. A well-prepared seedbed facilitates uniform germination and early seedling vigour, which are critical for establishing a competitive crop stand. Levelling of the field is equally important, as it ensures even distribution of rainwater and prevents the formation of waterlogged patches. In regions with uneven terrain, proper levelling also helps in reducing soil erosion and nutrient runoff.

In dryland agriculture, moisture conservation is a key consideration during land preparation. Practices such as conservation tillage, minimum tillage, and residue retention can be adopted to reduce soil moisture loss and improve water use efficiency. The incorporation of organic matter during land preparation further enhances soil structure, increases water-holding capacity, and promotes microbial activity.

Additionally, pre-sowing weed control measures are often integrated into land preparation. This may involve shallow cultivation or the use of stale seedbed techniques, where the field is irrigated or moistened to encourage weed germination, followed by their removal before sowing. Such practices help in reducing weed competition during the early stages of crop growth.

Overall, effective land preparation not only ensures better crop establishment but also lays the groundwork for efficient nutrient and water management throughout the crop growth cycle, ultimately contributing to higher productivity and sustainability (Rangaiah et al., 2024).

4. Variety Selection: The choice of suitable varieties plays a critical role in achieving higher yields and better adaptability. Improved varieties such as GPUK-3, RK-390-25, JK-155, and CO-3 have been developed with enhanced yield potential, disease resistance, and adaptability to diverse agro-climatic conditions. Selection of location-specific varieties is essential for optimizing productivity.

5. Seed Management and Sowing Practices: High-quality seeds with good germination capacity are essential for successful crop establishment. The recommended seed rate ranges from 8 to 12 kg per hectare depending on the method of sowing. Line sowing is preferred over broadcasting as it facilitates better intercultural operations and uniform plant

growth. The ideal spacing is generally maintained at 20–30 cm between rows and about 10 cm between plants. Sowing is typically done during the Kharif season, coinciding with the onset of monsoon rains, which ensures adequate soil moisture for germination and early growth (Kashyap et al., 2025).

6. Nutrient Management: Although kodo millet can grow under low nutrient conditions, the application of balanced fertilizers significantly enhances crop performance. The recommended dose of nutrients is generally around 40:20:20 kg N:P:K per hectare. Nitrogen is usually applied in split doses, with half applied at sowing and the remaining during the tillering stage to improve nitrogen use efficiency. The incorporation of organic manures such as farmyard manure or compost improves soil structure, enhances microbial activity, and contributes to long-term soil fertility. Integrated nutrient management practices combining organic and inorganic sources are considered most effective for sustainable production (Rangaiah et al., 2024).

7. Water Management: Kodo millet is primarily a rainfed crop and requires minimal irrigation. However, moisture availability during critical growth stages such as tillering and flowering is crucial for achieving higher yields. In regions with erratic rainfall, supplemental irrigation may be provided to avoid moisture stress. Efficient water management practices, including moisture conservation techniques such as mulching, can further improve crop performance.

8. Weed Management: Weeds pose a significant challenge during the early stages of crop growth, as they compete for nutrients, water, and light. Effective weed management is essential for ensuring optimal crop growth and yield. Manual weeding or mechanical weeding is commonly practiced, with the first weeding carried out around 15–20 days after sowing and the second at 30–35 days after sowing. Adoption of line sowing facilitates easier weed control and improves crop stand.

9. Pest and Disease Management: Kodo millet is relatively resistant to major pests and diseases, which reduces the need for chemical interventions. However, occasional infestations of pests such as shoot fly and diseases like leaf spot may occur. Integrated pest management strategies, including cultural practices, use of resistant varieties, and need-based application of plant protection measures, are recommended to minimize crop losses.

10. Intercropping and Cropping Systems: Kodo millet is often grown in mixed or intercropping systems with pulses and oilseeds, which enhances land use efficiency and provides additional income to farmers. Such systems also improve soil fertility through biological nitrogen fixation and reduce the risk of total crop failure under adverse conditions.

11. Harvesting and Yield: The crop matures within 90–120 days depending on the variety and environmental conditions. Harvesting is carried out when the panicles turn brown and the grains become hard. The plants are cut, dried, and then threshed to separate the grains. The average yield of kodo millet ranges from 800 to 1500 kg per hectare under traditional practices, but it can be significantly increased with improved production technologies and better management practices.



Post-Harvest Technology of Kodo Millet

Post-harvest management of kodo millet is crucial for maintaining grain quality, reducing losses, and enhancing its market value. One of the major challenges in post-harvest processing is the removal of the hard husk, which requires specialized de-husking techniques. Traditional methods are labour-intensive, but modern mechanical dehullers have improved efficiency and reduced processing time.

Drying is an essential step in post-harvest management. The grains must be dried to a safe moisture level of around 10–12 percent to prevent microbial growth and spoilage. Sun drying is commonly practiced, although mechanical drying methods are also being adopted in some regions.

Proper storage is critical to prevent post-harvest losses. Kodo millet grains are relatively resistant to storage pests compared to other cereals, but improper storage conditions can lead to moisture absorption and fungal infestation. The use of airtight containers, improved storage structures, and moisture control techniques ensures longer shelf life and better grain quality.

Processing and value addition play a significant role in enhancing the economic value of kodo millet. The grains can be processed into flour and used in the preparation of various traditional and modern food products, including porridge, bakery items, snacks, and ready-to-eat foods. Fermented products made from kodo millet have also gained popularity due to their enhanced nutritional and sensory qualities.

Despite its advantages, post-harvest losses remain a challenge due to inadequate processing infrastructure, lack of awareness, and limited access to modern technologies. The development of efficient processing equipment and value chain improvements can significantly enhance the utilization and commercialization of kodo millet.

Future Prospects

Kodo millet holds significant promise in addressing the challenges of food security, nutritional deficiencies, and climate change. Its resilience to abiotic stresses and low input requirements make it a key crop for sustainable agriculture. With increasing global interest in functional foods and health-conscious diets, kodo millet has the potential to gain wider acceptance in both domestic and international markets. Research efforts should focus on the development of high-yielding and stress-tolerant varieties, improved agronomic practices, and efficient post-harvest technologies. Policy support, awareness campaigns, and value chain development are essential to promote its cultivation and consumption.

Conclusion

Kodo millet is a highly valuable crop with multifaceted benefits, including nutritional richness, climate resilience, and adaptability to marginal environments. Scientific cultivation practices and improved post-harvest technologies can significantly enhance its productivity and profitability. As a sustainable and nutritious cereal, kodo millet has the potential to play a crucial role in future agricultural systems and contribute to global food and nutritional security.

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Evolution of Resource Harvesting Organs of Insect and Significance of Plants in Sustenance of Insect Diversity

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Akbari, D. A.[1], Shinde, C. U.[2], Bagul, G. D.[3]

[1&3]Ph.D. Scholar, Department of Entomology, NMCA, NAU, Navsari (Gujarat, India).

[2]Associate Professor, Department of Entomology, NMCA, NAU, Navsari (Gujarat, India).

Abstract

Insects make up about 60% of all known eukaryotic species, and their remarkable variety is mostly due to their long-standing evolutionary linkages to plants. Because plants provide food, shelter, and breeding grounds, insects have developed unique adaptations. The variety of mouthparts (chewing, siphoning, piercing-sucking, sponging and cutting-sponging) and ovipositors reflects a continuous coevolutionary arms race with plant defenses. These structural modifications allow insects to efficiently use a wide range of plant resources. Plant-insect interactions also boost insect resilience through dispersal opportunities, detoxifying processes, habitat refugia and nutritional flexibility. Fossil data suggests that strong plant relationships may have improved insect survival during major extinction events, including the Cretaceous-Paleogene extinction event. Typically, plants provide the ecological foundations and evolutionary factors that affect insect adaptability, resilience and the global conservation of insect species.

Keywords: Plant-insect coevolution, adaptive evolution, resilience, biodiversity, host specialization.

Introduction

Over 60 per cent of all eukaryotic species have been recognized as insects; this enormous diversity has mostly resulted from their intimate relationships with plants. Plants are vital sources of food for many insect species, including leaves, nectar, pollen, sap, wood, fruits, and seeds. In order for insects to obtain these plant-derived resources, they have developed specialized anatomical traits. This abundance of resources has been a key evolutionary factor. Concurrently, plants have evolved a variety of defense mechanisms, leading to an ongoing evolutionary interaction between the two species. In addition to affecting the shape and behaviour of insects, this co-evolutionary process also helps them adapt to changing environmental conditions and is crucial to the emergence and maintenance of insect biodiversity (War *et al.*, 2012).

Evolution of Resource Harvesting Organs

Insects have adapted to particular plant resources and counter adapted to plant defenses, as evidenced by the remarkable morphological diversity of their mouthparts and ovipositors.

1. Mouthpart Diversification:

a. Chewing (Mandibulate): For biting and grinding solid plant materials like leaves, bark, seeds, and wood, chewing mouthparts are the most basic and primordial form. This kind is common in early-evolved herbivorous insects, such as beetles and grasshoppers. Its purpose is to enable the insect to physically chew and break down solid food. Depending on the plant tissue, these insects exhibit changes in the strength and shape of their mandibles; for example, wood-boring beetles have mandibles that are severely sclerotized (Labandeira, 1997).

Examples:

i. Grasshoppers feed by chewing tough grasses and plant leaves.
ii. Caterpillars of butterflies and moths eat whole leaves and can strip plants completely.
iii. Leaf beetles typically chew on particular host plants, such as potatoes or soybeans.
iv. Bark beetles tunnel into trees and consume the inner bark, interfering with the tree's nutrient transport.
v. Weevils use their strong mouthparts to bore into seeds, fruits, or plant stems.

b. Siphoning: Siphoning mouthparts are a defining feature of adult butterflies and moths and are specifically adapted for nectar feeding. These insects possess an elongated, flexible, and coiled structure known as a proboscis, which allows them to efficiently draw liquid food (Krenn & Penz, 1998).

i. Function: The proboscis enables access to nectar located within deep or narrow floral tubes that are otherwise difficult to reach.

ii. Adaptations: These mouthparts evolved in close association with flowering plants (angiosperms). Variations in floral structure, particularly corolla length and nectar depth, have influenced the diversification and length of the proboscis (Johnson *et al.*, 2023).

Examples:

i. *Danaus plexippus* utilizes its proboscis to obtain nectar from milkweed flowers (Kevan & Baker, 1983).

ii. *Xanthopan morganii* possesses an exceptionally long proboscis (20–30 cm), corresponding precisely with the deep nectar spur of *Angraecum sesquipedale* (Wasserthal, 1997).

iii. Papilio species (swallowtails) also show selective feeding behavior linked to floral characteristics.

c. Piercing-Sucking: Piercing–sucking mouthparts are specialized for penetrating plant or animal tissues to withdraw fluids such as sap, xylem, or blood. This feeding system generally consists of needle-like stylets enclosed within a protective sheath (Tjallingii, 2006).

i. Function: They enable insects to access internal fluids, including phloem sap and cellular contents.

ii. Adaptations: In certain insects like aphids, saliva contains effector molecules that interfere with plant defense mechanisms, allowing them to feed with minimal detection (Backus et al., 2005).

Examples:

i. Aphids insert their stylets between plant cells to reach phloem sap and are important transmitters of plant viruses (Walling, 2008).

ii. Whiteflies extract plant sap, leading to reduced photosynthetic activity and the excretion of honeydew.

iii. Cicadas use elongated, robust stylets to draw xylem sap from tree stems and branches.

iv. Culicidae (mosquitoes), though primarily animal feeders, exhibit comparable piercing behavior when consuming blood or nectar (Hunter & Ullman, 1992).

D. Sponging: This form of mouthpart is typical of many flies and is adapted for consuming exposed liquid substances. The labella act like sponge-like pads that absorb fluids directly from surfaces (Chapman, 2013).

i. Function: They are used to lap up nectar, plant exudates, and liquids derived from decaying organic material.

ii. Adaptations: The labella contain fine channels known as pseudo-tracheae—minute grooves that facilitate liquid uptake through capillary action. However, these mouthparts are not capable of penetrating solid tissues.

Examples:

i. *Musca domestica* feeds on sugary liquids and decomposing organic matter using sponging mouthparts (Nation, 2008).

ii. Flesh flies consume both animal secretions and sugar-rich plant fluids.

iii. Blowflies are attracted to floral nectar as well as carrion (Clements, 1992).

e. Cutting-Sponging: This mouthpart type combines cutting and sponging mechanisms. It is characteristic of certain biting flies, where the insect first slices the surface and then absorbs the released fluids (Foil & Hogsette, 1994).

i. Function: The mouthparts cut through tissue and subsequently sponge up the exposed blood or plant sap.

ii. Adaptations: These insects are well adapted for rapid feeding. They typically possess sharp, blade-like structures for creating wounds, along with strong flight ability that allows quick access to hosts and fast escape after feeding.

Examples:

i. Tabanidae (horseflies) use cutting mandibles to lacerate skin or plant tissue and then lap up the flowing blood or sap (Lehane, 2005).

ii. Biting midges, belonging to the family Ceratopogonidae, pierce the skin to feed on blood and may also consume nectar (Krenn, 2010).

2. Ovipositor Specialization: The ovipositor is a tubular or blade-like structure located at the posterior end of many female insects and serves as an essential reproductive adaptation for egg deposition. In plant-associated species, ovipositor specialization is particularly important for bypassing plant defenses, securing suitable sites for larval development, and supporting species persistence and coevolutionary interactions (Price, 2003). The form and function of the ovipositor differ considerably among insect groups, reflecting their ecological roles and diverse reproductive strategies.

a. Penetration and Egg Deposition within Plant Tissues: Certain insects have evolved ovipositors specifically modified for embedding eggs inside plant structures. Members of the suborder Symphyta (sawflies) possess distinctly serrated ovipositors that function like miniature saws, enabling them to incise leaf tissues prior to oviposition. By placing eggs within plant tissue rather than on the surface, they enhance protection against predators and adverse environmental conditions (Price, 2003). Parasitic wasps belonging to the families Braconidae and Ichneumonidae exhibit highly elongated, needle-like ovipositors adapted for insertion into stems, buds, and leaf substrates. These structures are frequently reinforced with metal ions such as zinc, increasing their rigidity and enabling penetration of dense plant tissues or even woody bark (Vincent & King, 1995). The wood-boring wasp *Sirex noctilio* demonstrates an even more specialized mechanism. Its drill-like ovipositor bores into coniferous wood, and during egg deposition it simultaneously introduces symbiotic fungal spores. These fungi colonize the host tissue and create a suitable nutritional environment for developing larvae (Vincent & King, 1995).

b. Telescoping Ovipositors for Deep Placement: Fig wasps exhibit remarkably specialized, telescopic ovipositors that enable egg deposition deep within the enclosed inflorescence (syconium) of figs. These ovipositors are elongated, flexible, and equipped with sensory setae that assist in maneuvering through the complex internal floral architecture. For example, species of Pegoscapus place their eggs inside fig florets while simultaneously facilitating pollination (Weiblen, 2002). Similarly, gall-forming wasps and gall midges employ slender ovipositors to insert eggs into meristematic or other plant tissues. Their oviposition activity stimulates the development of galls abnormal plant growths that provide both nourishment and protection for the developing larvae (Stone and Schönrogge, 2003).

c. Surface Attachment with Adhesive Secretions: Insects such as butterflies in the family Papilionidae and leafhoppers belonging to Cicadellidae commonly fasten their eggs to leaves, stems, or floral structures using adhesive secretions. These glue-like substances secure the eggs to the plant surface and reduce the risk of dislodgement by rain or wind, while also lowering exposure to predators (Zalucki *et al.,* 2002). The cabbage white butterfly, *Pieris rapae*, lays its eggs individually on host plant foliage. Each egg is coated with a sticky material that ensures firm attachment to the leaf surface. Insects that produce ootheca, such as mantids (order Mantodea) and cockroaches (order Blattodea), enclose their eggs within protective cases that are securely affixed to vegetation or bark. These structures provide mechanical protection as well as camouflage, enhancing egg survival (Nation, 2008).

d. Oviposition Inside Fruits and Stems: Fruit flies in the family Tephritidae have well-developed, pointed ovipositors that enable them to place eggs just beneath the surface of fruits such as mango, guava and citrus. This concealed deposition allows larvae to complete development within the fruit tissue, where they feed in relative protection. For instance, *Bactrocera dorsalis* infests ripening mangoes by inserting eggs under the peel; the emerging maggot's tunnel through the pulp, leading to internal decay and significant economic losses (White & Elson-Harris, 1992). The rice stem borer, *Scirpophaga incertulas*, lays its eggs close to the base of the leaf sheath. This strategic placement allows newly hatched larvae to quickly bore into the stem, reducing their exposure to predators and environmental hazards (Heinrichs *et al.,* 1985).

Plants as the Foundation of Insect Resilience

Resilience: the capacity to tolerate or rebound from disturbances is strongly influenced by plant-insect interactions. Plants supply essential resources such as nutrition and habitat, while long-term coevolution between plants and insects has produced adaptations that improve insect survival under environmental stress, habitat fragmentation and human-induced pressures.

1. Resource Buffering: Dietary Flexibility Enhances Stability: When primary hosts become scarce or inappropriate owing to stressors like drought, herbivory, or pollution, diverse plant communities provide the insects with alternate food sources, acting as ecological insurance. When preferred hosts are not available, pollinators and parasitoids are sustained by nectar and pollen from non-host plants (Forister *et al*., 2015). The capacity to alter hosts allows polyphagous insects, such as many Lepidoptera and Coleoptera, to have more stable populations (Jaenike, 1990).

Example: Despite milkweed (*Asclepias* spp.) is the primary nectar source for monarch butterflies (*Danaus plexippus*), they can use other sources while migrating (Brower *et al.,* 2015).

2. Refugia: Microhabitats buffer environmental extremes:

a. Complex plant structures that provide essential microhabitats, such as leaf litter, shield soil-dwelling insects from heat, protect insects from temperature extremes (Lövei & Sunderland, 1996). Desiccation (for example, beetles find moisture in the cracks in the bark). Pesticides and predators (for example, thick foliage protects aphids from parasitoid wasps) (Gurr *et al.,* 2017).

b. Example: Hedgerows and plant detritus that act as refuges allow ground beetles to survive in fields (Holland & Luff, 2000).

3. Coevolutionary "Arms Race": Pre-Adaptation to Novel Stressors: Through prolonged coevolution with their host plants, many insects have developed physiological and behavioural adaptations such as cytochrome P450–mediated detoxification in Lepidoptera and protective behaviours like leaf-rolling that originally evolved to counter plant defensive compounds (e.g., alkaloids) but incidentally enhance tolerance to synthetic insecticides, as exemplified by *Manduca sexta*, which metabolizes nicotine using P450 enzymes and consequently exhibits reduced susceptibility to certain chemical controls.

4. Dispersal and Recolonization: Landscape connectivity supported by continuous vegetation and stepping-stone habitats plays a vital role in facilitating insect dispersal and recolonization following disturbances such as fire, storms, or habitat fragmentation. For example, field margins enriched with native flora enhance movement corridors for pollinators and natural enemies (Haddad *et al.,* 2015), while urban green spaces function as refugial habitats within human-dominated environments (Baldock *et al.,* 2019). The persistence of the *Melitaea cinxia* in fragmented landscapes further illustrates how plant-mediated connectivity promotes dispersal and long-term population stability (Hanski, 2011).

5. Paleontological Resilience: Survival Through Mass Extinctions: Plant-Insect Relationships and Survival: Insects that maintained strong associations with diverse and widely distributed plant lineages—such as beetles linked to gymnosperms and pollinators specialized on angiosperms—appear to have experienced greater survival during major extinction events (Labandeira & Sepkoski, 1993). These plant–insect relationships provided continued access to food resources, shelter and breeding sites, thereby sustaining insect populations even as many other organisms declined or disappeared.

The K-Pg (Cretaceous-Paleogene) Extinction – 66 million years ago:

a. During the Cretaceous–Paleogene extinction event, approximately 66 million years ago, the impact of a large asteroid triggered profound environmental disruptions that led to the extinction of numerous species, including non-avian dinosaurs. Plant communities were also heavily affected, as many ancient floral lineages declined or vanished, resulting in significant shifts in vegetation structure and composition.

b. Despite the severe ecological upheaval, numerous plant-associated insects persisted through the crisis. In particular, species that relied on flowering plants (angiosperms) for feeding or pollination demonstrated greater resilience and adapted more successfully to post-extinction environments than insects primarily dependent on declining gymnosperm lineages (Condamine *et al.*, 2016).

Example:

a. Beetles showed rapid recovery: Their broad feeding habits and long-term evolutionary ties with plants particularly flowering plants (angiosperms) enhanced their survival and enabled swift diversification after the extinction event (McKenna *et al.*, 2019). Many beetle lineages had already evolved the ability to exploit a variety of plant resources, including flowers, fruits, wood, and pollen, which allowed them to adjust effectively to the restructured post-extinction vegetation landscape. Several key factors contributed to the comparatively higher survival of plant-associated insects during periods of environmental crisis:

b. Dietary flexibility: Species capable of utilizing multiple plant taxa or feeding on different plant tissues were less severely impacted by the disappearance of particular host plants (Labandeira & Sepkoski, 1993).

c. Coevolution with angiosperms: As flowering plants rebounded and diversified following the extinction event, insects closely linked to them diversified in parallel, reinforcing mutual adaptive success (Condamine *et al.*, 2016).

c. Broad geographic distribution: Insects occupying a wide range of habitats were less susceptible to localized extinction events, increasing their overall chances of persistence (McKenna *et al.*, 2019).

Role of Plants for Sustenance of Insect Diversity

Plants form the ecological and evolutionary base of insect diversity through several fundamental processes.

1. Drivers of Insect Evolutionary Diversification:

a. Coevolutionary diversification:

i. Plants develop innovative defensive traits—such as toxic secondary metabolites and structural barriers like trichomes—to reduce herbivory, enabling them to diversify and escape intense insect pressure.

ii. In response, insects evolve counter-adaptations, including specialized detoxification systems and behavioural strategies, which allow them to exploit these defended plants and subsequently undergo adaptive radiation.

iii. A classic example is the coevolutionary interaction between milkweed plants (genus Asclepias) and the monarch butterfly, *Danaus plexippus*, illustrating reciprocal evolutionary change (Ehrlich & Raven, 1964).

b. Host Specialization and Sympatric Speciation:

i. Divergent selective pressures imposed by different host plants can promote ecological specialization in insect populations, gradually restricting gene flow between groups associated with alternative hosts.

ii. Trade-offs in host-specific mating preferences or larval performance further reinforce reproductive isolation, potentially leading to the formation of new species without geographic separation.

iii. A well-documented case is *Rhagoletis pomonella*, in which a host shift from hawthorn to apple resulted in sympatric divergence and incipient speciation (Feder *et al.*, 1988).

c. Pollinator-Mediated Diversification:

i. Highly specialized plant–pollinator interactions, such as orchid–bee and fig–wasp systems, drive reciprocal evolutionary modifications in both partners.

ii. Floral characteristics—including color, scent, and structural morphology—co-evolve with pollinator traits such as tongue length, sensory preferences and foraging behavior, strengthening reproductive isolation among plant populations.

iii. An illustrative example is the relationship between Disa orchids and long-tongued flies in South Africa, where pollinator specificity has promoted floral diversification (Johnson, 2006).

2. Providers of Food Resources:

a. Nectar and pollen serve as primary energy sources for adult pollinators such as bees and butterflies, directly supporting survival and reproduction.

b. Foliage provides nourishment for herbivorous larvae and adults, including caterpillars and beetles, many of which exhibit strong host specificity.

c. Fruits and seeds are essential for frugivorous insects like fruit flies and for seed-feeding beetles such as bruchids.

d. Sap and phloem fluids sustain sap-feeding groups including aphids and leafhoppers.

3. Creators of Habitats and Microhabitats:

a. Physical structures:

i. Leaf litter forms a refuge for ground-dwelling insects such as carabid beetles and springtails.

ii. Bark crevices provide shelter and breeding space for bark beetles and ants.

iii. Galls, induced by insects, create enclosed microenvironments that house developing gall wasps and midges.

b. Nesting sites:

i. Hollow plant stems serve as nesting chambers for solitary bees.

ii. Rolled or tied leaves function as protective shelters for caterpillars.

4. Facilitators of Ecosystem Processes:

a. Nutrient cycling: Decomposer insects, including dung beetles and termites, break down plant-derived organic matter, accelerating decomposition and enhancing soil fertility.

b. Symbiotic interactions: In ant–plant mutualisms, such as those involving Acacia species and protective ants, plants provide food and shelter while ants defend against herbivores. Certain beetles, such as ambrosia beetles, cultivate symbiotic fungi within tree tissues, forming tightly integrated insect–plant–microbe systems.

5. Promoters of Community Biodiversity:

a. Niche partitioning:

i. Vertical stratification allows distinct insect communities to occupy canopy versus understory layers.

ii. Chemical specialization enables insects to exploit specific plant secondary metabolites, reducing interspecific competition.

b. Biodiversity hotspots: Tropical rainforests, characterized by exceptional plant diversity, support the highest levels of insect richness and specialization (Novotny *et al.*, 2006).

6. Buffers of Climate Variability:

a. Microclimate regulation: Forested ecosystems moderate temperature and humidity extremes, creating stable conditions that protect insect populations from climatic stress.

b. Phenological synchrony: Seasonal patterns of flowering and fruiting align with insect life cycles, ensuring resource availability for pollinators and seed-associated species.

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Role of Insect Gut Bacteria in Insecticide Resistance

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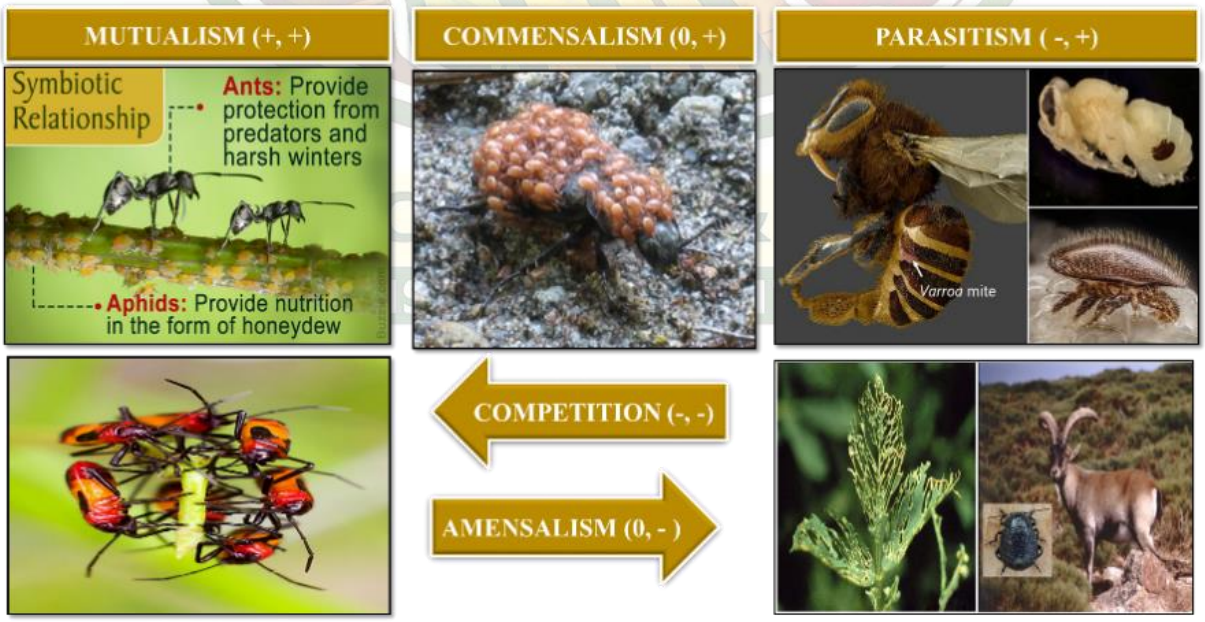
Darji, T. R.[1], Patel, K. M.[2], Shinde, C. U.[3]
[1]Ph.D..Scholar, Department of Entomology, NMCA, NAU, Navsari (Gujarat, India).
[2]Assistant.Professor, Department of Entomology, NMCA, NAU, Navsari (Gujarat, India).
[3]Associate Professor, Department.of Entomology, NMCA, NAU,.Navsari (Gujarat, India).

Abstract
Resistance to insecticides is a major problem in agriculture and public health. Insect resistance development is a global concern. This review highlights the crucial role of insect gut bacteria in mediating insecticide resistance. Gut bacteria can confer resistance through various mechanisms, including metabolic detoxification of insecticides, modulating the host's immune response, and enhancing insect fitness. Several case studies demonstrate how specific bacterial species, such as *Burkholderia*, *Enterococcus silesiacus*, *Sphingomonas*, and *Serratia marcescens* can degrade insecticides and increase insect resistance. Understanding the complex interactions between insects and their gut microbiomes is essential to develop sustainable pest management strategies that take into account the role of these microbial symbionts. Future research should focus on elucidating the molecular mechanisms of resistance-induced bacterial emergence, characterising gut microbiomes in different insect species and exploring the potential of targeting gut bacteria as a new approach to pest control.

Keywords: Insect gut bacteria, insecticide resistance, symbiosis, endosymbionts, bacterial-mediated resistance, insect gut microbiome, etc.

Introduction
The word “symbiosis” is a greek word which means the coexistence of dissimilar organisms. In 1877, Albert Frank used the term “symbiosis” that refer to “any situation where two distinct species live on or within one another.” Symbiosis means an organism that lives in symbiosis. In insects, symbionts are often beneficial to, or even required by, the insect host. Around 15 to 20 per cent of insects are believed to be in symbiotic relationships with bacteria (Zhou *et al.*, 2021). Wigglesworth (1929) first described the insect and microorganism interplay forming mutualistic associations. In insects, these symbionts play a variety of roles, including enhancing nutrition, aiding in reproduction, and conferring resistance to environmental stressors. This article delves into the mechanisms through which gut bacteria influence insecticide resistance.

Different Symbiotic Relationships



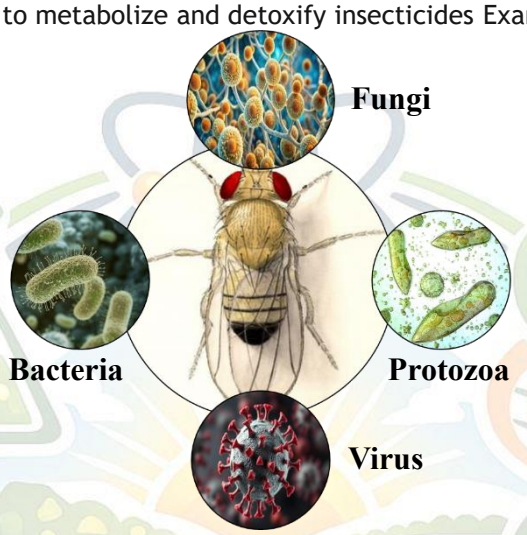
Different Types of Symbionts
1. **Ectosymbionts:** An ectosymbiont is one which lives outside of its host’s cells.
2. **Endosymbionts:** An endosymbiont is one which lives inside of its host’s cells.

a. Primary Endosymbiont/Essential Endosymbiont: They are essential for host growth, development and survival. They provide essential nutrients to its host. They were housed in a specialized structure called as bacteriocytes. They were obligative in nature and are transmitting from one generation to another (vertical transmission). *E.g., Wolbachia* spp., *Buchnera aphidicola, etc.* (Rahman *et al.,* 2022)

b. Secondary Endosymbionts/Facultative Endosymbionts: They are not necessary for its host growth and development but with their presence increases the fitness of the host which enhancing host resistance towards heat stress and detoxification of insecticides *etc.* They transmitted among individuals of the same generation (horizontal transmission). *E.g., Serratia symbiotica, Enterococcus silesiacus, Citrobacter freundii, Burkholderia* spp., *etc.* (Rahman *et al.,* 2022)

Different Microorganism Act as Endosymbiont in Insect

Endosymbionts are microorganisms that live within the bodies or cells of their host organisms, forming mutualistic relationships. The symbiotic relationship between insects and their gut microbiota extends beyond nutrition and immunity, encompassing the capacity to metabolize and detoxify insecticides Examples of endosymbionts include:



Bacteria as Endosymbionts

Insect Pest	Endosymbiont
Bark beetles	*Enterobacter spp.*
Tephritid olive fruit fly	*Candidatus erwinia dacicola*
Aphids	*Buchnera aphidicola*
Drosophila	*Spiroplasma*

Fungi as Endosymbionts

Insect Pest	Endosymbiont
Dosophila melanogaster	yeasts
Brown plant hopper	Yeast like symbionts
many bark beetles	yeasts
Bark beetles	*Ophiostoma spp.*

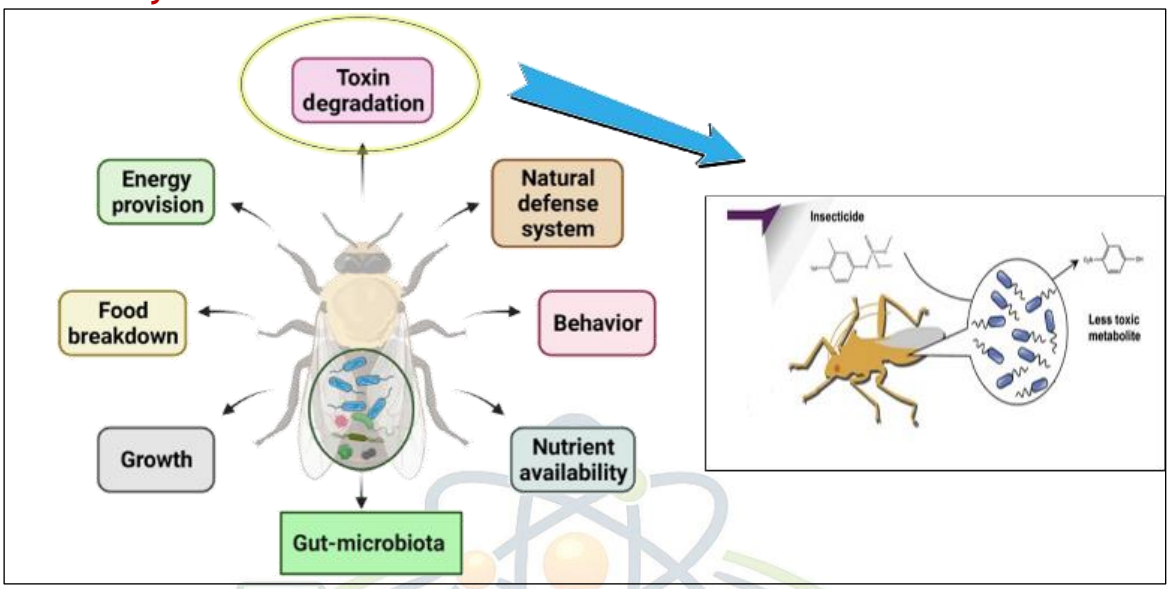
Viruses as Endosymbionts

Polydnaviruses are a unique group of viruses that form a symbiotic relationship with certain parasitoid wasps. These wasps, belonging to the Ichneumonidae and Braconidae families, carry these viruses within their reproductive organs. During oviposition (egg-laying), the wasp injects the virus into its host insect. This viral infection suppresses the host's immune system, creating a favorable environment for the wasp's offspring to develop within the host. In essence, the virus acts as a biological weapon, manipulating the host's immune response to benefit the wasp. (Rahman *et al.,* 2022)

Protozoa as Endosymbionts

Termites, known for their ability to digest wood, rely heavily on a diverse community of gut microbes, including protozoa. These flagellates break down the complex cellulose in wood into simpler sugars that the termite can then absorb.

Functions of Endosymbionts



The gut microbiota in insects performs a range of essential functions that influence their survival, development, and adaptability: energy provision, food breakdown, growth enhancement, nutrient availability, behavioral regulation, natural defense mechanisms, and toxin degradation (Siddiqui *et al.*, 2022). In insects, gut bacteria play a key role in the metabolism and neutralisation of harmful substances, including plant secondary metabolites, pollutants, and synthetic insecticides. Microbes in the gut enzymatically modify the toxin into a less toxic metabolite, which reduces its harmful impact on the host.

Pesticide Detoxification

Endosymbionts may contribute to the development of resistance to pesticides in insect populations by developing mechanisms for detoxification of specific pesticides and thus protecting the insect host. The ways in which gut bacteria induce host resistance to insecticides mainly include the following four: (1) Gut bacteria provide compounds to the host to enhance host resistance; (2) gut bacteria degrade pesticides by their own pesticide degrading genes; (3) gut bacteria activate the host's immune system to degrade pesticides and (4) gut bacteria compete with harmful bacteria for ecological niches to enhance host resistance (Han *et al.*, 2024).

Several studies highlight the role of symbiotic bacteria in conferring insecticide resistance:

Pseudomonas melophthora, an obligatory extracellular bacterial symbiont of the apple. maggot *Rhagoletis pomonella* (Walsh), has demonstrated degradation activities against dichlorovos, diazinon, parathion, dieldrin, and carbaryl, according to Boush and Matsumura's 1967 report on the first instance of microbiome-facilitated resistance.

***Burkholderia* in Bean Bugs:** According to Kikuchi *et al*. (2012) bean bug, *Riptortus pedestris*, possesses beneficial gut symbiotic bacteria belonging to the Burkholderia genus, which are obtained by nymphal insects from the surrounding soil with each generation. The Burkholderia strains that degrade fenitrothion form a distinct and advantageous symbiotic relationship with the stinkbugs, providing them with a level of resistance to fenitrothion. These bacteria break down fenitrothion into 3-methyl-4-nitrophenol and utilize the resulting product as a carbon source for their growth.

***Citrobacter* in Fruit Flies:** Cheng et al. (2017) revealed that the gut symbiont *Citrobacter freundii* (CF-BD) is essential for breaking down the organophosphate insecticide trichlorphon in the fruit fly species *Bactrocera dorsalis*. A comparative genomic analysis showed that CF-BD contains phosphatase hydrolase genes that facilitate trichlorphon degradation, and the expression of these genes increased in the presence of trichlorphon. Additional experiments validated CF-BD's role in conferring resistance to trichlorphon. Fruit flies that were inoculated with CF-BD demonstrated greater resistance to trichlorphon than those in the control group. The research also clarified the degradation pathway, revealing that CF-BD breaks trichlorphon down into chloral hydrate and dimethyl phosphite.

***Burkholderia* in rice bug:** Ishigami *et al*. (2021) revealed that *Cletus punctiger* can acquire *Burkholderia*, a bacterium capable of degrading fenitrothion, through oral infection. This bacterium colonizes the midgut crypts of the rice bug. In vitro assays confirmed that the gut-colonizing *Burkholderia* retains its ability to degrade fenitrothion within the insect gut. Furthermore, rice bugs harboring this bacterium exhibited significantly higher resistance to fenitrothion treatment compared to those without.

Enterococcus in Cotton Leafhoppers: Sivakumar *et al*. (2022) shown that Enterococcus silesiacus, obtained from the gut of the leafhopper *Amrasca biguttula biguttula*, has the capability to break down imidacloprid. This bacterium exhibited higher carboxylesterase enzyme activity, which leads to degradation of the imidacloprid. This finding suggests

that *E. silesiacus* may play a role in the detoxification of imidacloprid within the leafhopper, potentially contributing to insecticide resistance.

Sphingomonas in Aphids: Nannan *et al*. (2023) Imidacloprid can be broken down by Sphingomonas that was isolated from the intestines of *Aphis gossypii*. To determine the role of *Sphingomonas* in imidacloprid resistance, imidacloprid-resistant (*IMI-R*) strain are treated with antibiotics to eliminate gut bacteria. This led to a significant increase in the aphid's susceptibility to imidacloprid. Conversely, supplementing the imidacloprid-susceptible (*IMI-S*) strain with *Sphingomonas* resulted in a significant decrease in susceptibility. HPLC analysis revealed that *Sphingomonas* metabolized imidacloprid with an efficiency of 56%, suggesting that it degrades the insecticide through hydroxylation and nitroreduction.

Serratia in Bean Bugs: According to Xia *et al*. (2023) the soybean pest *R. pedestris* established a symbiotic relationship with *Serratia marcescens* strain with organophosphorus pesticide degrading activity, thereby facilitating the development of insecticide resistance to insect pests. They isolate *S. marcescens* from the midgut of *R. pedestris*. This bacterium exhibited phosphorus-solubilizing activity and demonstrated the ability to degrade dimethoate, an organophosphate insecticide, as confirmed by GC-MS analysis. Further analysis revealed that *S. marcescens* possesses genes encoding MBL-fold metallo-hydrolases, enzymes known to degrade organophosphorus compounds.

Conclusion

The gut microbiota has a significant role in insecticide resistance, revealing a complex interaction between insect hosts and microbial symbionts. The gut bacteria confer resistance through various mechanisms including metabolic detoxification, immune modulation and influencing insect fitness. These interactions is essential for developing effective pest management strategies and mitigating the growing problem of insecticide resistance. The different bacteria, *viz., Burkholderia, E. silesiacus, Sphingomonas* and *S. marcescens* have been found to confer resistance to insecticides like fenitrothion, trichlorphon, imidacloprid and dimethoate in various insect species (*R. pedestris, B. dorsalis, A. biguttula biguttula* and *A. gossypii*). The resistance is often mediated by bacterial degradation of insecticide. Additionally, antibiotic treatment can disrupt symbiosis and increase insect susceptibility to insecticides. This information highlights the importance of considering gut bacterial resistance to insecticides and of developing new pest control strategies targeting these symbionts.

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Advances in Bioethanol Production from Potato in India

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Firdusur Rahman[1]

[1]Department of Horticulture (Vegetable Science), Faculty of Agricultural Sciences, Rajiv Gandhi University, Arunachal Pradesh (791112).

Abstract

India's position as a major potato producer offers a promising, yet underutilized, opportunity to produce bioethanol from surplus and waste potatoes. It examines the technical, economic and policy frameworks surrounding this initiative emphasizing its potential to help meet India's national ethanol blending goals without compromising food security. It also highlights how technological advancements in starch hydrolysis and simultaneous saccharification and fermentation (SSF/SiSF) can enhance yields. While challenges such as production costs and the food Vs fuel debate persist, strategic use of cull tubers, processing waste, and seasonal surpluses offers a sustainable route to strengthen energy security, reduce carbon emissions, and generate rural employment.

Keywords: Bioethanol, ethanol blending, potato waste, sustainable energy, starch fermentation.

Introduction

India is fundamentally an agrarian economy with substantial agricultural output, including staple crops such as potatoes. The relentless rise in global energy consumption, driven by industrial expansion, urbanization and population growth has intensified concerns over environmental degradation, climate change and the finite nature of fossil fuels. This has spurred a global shift toward sustainable energy sources, with bioethanol emerging as a promising alternative to gasoline in the transportation sector. The rapid increase in global population, coupled with ongoing industrialization and modernization, has led to a substantial rise in energy demand worldwide. Currently, this demand is predominantly fulfilled by fossil fuels such as coal, petroleum, and natural gas. However, these energy sources are finite and contribute significantly to environmental issues, including greenhouse gas emissions, global warming, and ozone layer depletion. Continued reliance on fossil fuels is therefore unsustainable, as their reserves are expected to diminish with ongoing consumption (Sun & Cheng, 2002; Crookes, 2006).

In light of these concerns, there has been a growing shift toward renewable and environmentally friendly energy sources. Biofuels, particularly bioethanol, have emerged as promising alternatives due to their potential to reduce dependence on fossil fuels and mitigate environmental impacts. Bioethanol is produced through the fermentation of carbohydrates derived from various biomass sources, including sugar crops, starch-rich materials, and lignocellulosic residues (Demirbas, 2009; Liu & Lin, 2009).

Globally, the production and consumption of bioethanol have increased significantly, with countries such as the United States and Brazil leading in production. This trend highlights the growing importance of bioethanol as a sustainable energy source. The production process typically involves three main stages: hydrolysis of biomass into fermentable sugars, microbial fermentation of these sugars into ethanol, and purification through distillation (Alonso et al., 2010; Sadeghinezhad et al., 2014).

A variety of feedstock's can be utilized for bioethanol production, including sugarcane, maize, and potatoes. Among these, potatoes and their processing residues, such as potato peels, have gained attention due to their high content of starch and fermentable carbohydrates. Potato peels, in particular, contain significant amounts of cellulose, hemicellulose, and starch, making them an efficient substrate for ethanol production (Israilides et al., 2008).

What is Bioethanol?

Bioethanol is a high octane fuel produced mainly by the sugar or cellulose fermentation process. It serves as the principle petrol substitute and has replaced lead as an octane enhancer in gasoline. Bioethanol is suitable for flex-fuel vehicles and can be blended with gasoline in various ratios (e.g., E5 to E26, E85). Cellulosic biomass from non-food sources is also being developed as a feedstock, through starch-based crops like potato remain more immediately viable in many contexts.



Potential Crops for Bioethanol Production in India

Table 1: Potential Crops for bioethanol production in India (Kumar *et al.*,2024):

crop	Ethanol yield (litres/t)	Crop/stalk yield(t/ha)	Ethanol production (litres/ha)
Sugarcane	70	80	5600
Sugar beet	100	50.6	5060
Sweet potato	125	18.8	2350
Potato	110	20.9	2304
Maize	360	5.9	2133
Cassava	180	11.3	2034
Rice	430	4.7	2012
Wheat	340	3.4	1165
Sorghum	26.3	38.5	1013
barley	250	3.0	738

Global and National Context of Bioethanol Production

Global fuel ethanol production reached approximately 28,220 million gallons in 2022 with the USA and Brazil leading. India's production grew significantly from 450 million gallons in 2018 to 1230 million gallons in 2022.

India's National Biofuel Policy (2018) targets 20% ethanol blending in petrol by 2025. Ethanol supply increased from 38 crore litres (2013-14) to 502 crore litre (2022-23), with blending rising from 1.53% to 11.72% (Dey *et a*l., 2023).

Potato Cultivation and Suitability in India

India s among the top potato producer's worldwide. Key indian cultivars show high starch content, with varieties like **Kufri Surya (86% starch)** and **Kufri Himsona (high dry matter, low reducing sugars)** being particularly suitable. Potato peels contain 50-70% starch, providing an excellent waste feedstock (Vithu *et al.*, 2019).

Bioethanol Production Process

1. Feedstock Preparation: Biomass feed stocks are harvested and processed to extract the fermentable sugars. For example, sugarcane and corn are crushed to extract their juice or starch, while cellulosic materials are pretreated to break down the cellulose into fermentable sugars.

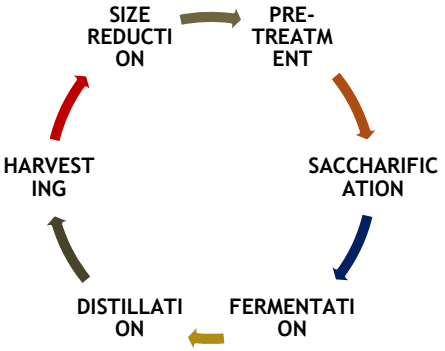
2. Fermentation: The extracted sugars are fermented using yeast or bacteria in the presence of water to produce ethanol and carbon dioxide. Yeast species such as Saccharomyces cerevisiae are commonly used in ethanol production due to their efficiency in converting sugars to ethanol.

3. Distillation: The fermented mixture undergoes distillation to separate the ethanol from the water and other components. Distillation involves heating the mixture to vaporize the ethanol, which is then cooled and condensed back into a liquid form.

4. Dehydration: The ethanol obtained from distillation typically contains some water, which needs to be removed to increase the ethanol concentration. Dehydration processes such as molecular sieves or membrane technologies are used to remove the water and produce anhydrous (pure) ethanol

5. Denaturing (optional): In some cases, ethanol is denatured by adding small amounts of substances such as gasoline or methanol to make it unsuitable for consumption as a beverage. Denatured ethanol is often used as a fuel additive or in industrial applications.

6. Byproduct Recovery: Throughout the production process, various byproducts such as carbon dioxide, stillage (residue from fermentation), and lignin (from cellulosic materials) are generated. These byproducts can be utilized for various purposes, including animal feed, biogas production, or as a source of additional revenue through further processing.



The process involves starch hydrolysis to sugars, followed by yeast fermentation. The key reaction is:

$$C_6H_{12}O_6 \xrightarrow{\text{Zymase}} 2\,C_2H_5OH + 2CO_2$$

Case Studies

Studies on production of bioethanol from waste potatoes using co-culture of saccharomyces cerevisiae and *aspergillus niger* (subhash *et al.*, 2016):

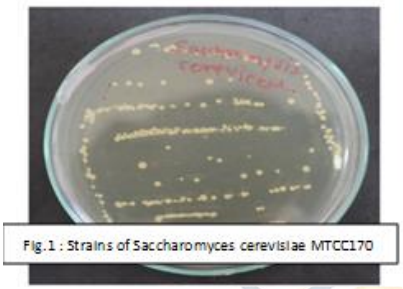


Fig.1 : Strains of Saccharomyces cerevisiae MTCC170



Fig.2 : Strains of Aspergillus niger MTTC 2196.

Maximum ethanol yields were observed under the following conditions:

1. At pH 4.5 and 25- 30℃ after 96 hours of incubation, yields reached up to 5.3%.
2. Higher incubation periods (120 hours) maintained stable yields around 4.0-4.3% across temperatures.
3. Residual sugar levels decreased significantly over time, dropping to as low as 0.045-0.080 mg/ml after 144 hours, indicating efficient conversion of starch to fermentable sugars and then to ethanol.

Conclusion

Potato-based bioethanol is a viable, sustainable option for India. It supports energy security, reduces emissions, adds value for farmers, and creates rural employment. Technological improvements in starch hydrolysis, fermentation, and biorefinery systems increase the efficiency and economic feasibility of potato-based ethanol. It also provides socio-economic benefits including value addition for farmers, reduced wastage, and enhanced rural employment. With focused research, technological upgrades, and supportive government policies, potato-based bioethanol can become an important part of India's sustainable.

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Biogeochemical Nutrient Dynamics and Soil Fertility in Tree-Based Agroecosystems

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Hiranmayee Nayak[1]
[1]Department Silviculture and Agroforestry, College of Forestry, OUAT.

Abstract
Soil fertility is essential for sustainable agriculture and forestry, but inefficient fertilizer use has led to soil degradation and increased greenhouse gas emissions. Globally, only 30–50% of applied nitrogen is utilized, while the rest contributes to pollution and nitrous oxide (N_2O) emissions, which are 273–298 times more potent than CO_2 (IPCC, 2021). Trees and agroforestry systems improve nutrient cycling through litter addition, deep nutrient uptake, and biological nitrogen fixation (up to 200 kg N ha^{-1} yr^{-1}). These systems can enhance nitrogen use efficiency by 20–40%, increase soil organic carbon, and reduce N_2O emissions by 15–30%, promoting sustainable and climate-resilient land use.

Introduction
Soil is the foundation of both agriculture and forestry, supporting plant growth and sustaining ecosystems. Much of the applied fertilizer is not efficiently used by crops, resulting in nutrient losses, environmental pollution, and long-term soil degradation (IPCC, 2021; Ladha *et al.*, 2020). Trees improve soil fertility by adding organic matter through leaf litter, enhancing nutrient recycling, and supporting beneficial soil microorganisms. Their deep root systems help access nutrients from deeper soil layers and reduce nutrient losses. Integrating trees with improved nutrient management practices can enhance fertilizer use efficiency, reduce greenhouse gas emissions, and protect the soil environment. Such approaches are essential for achieving sustainable and climate-resilient land use systems.

Soil Fertility and Nutrient Dynamics
A fertile soil is one that can supply essential nutrients to plants in adequate amounts and proper balance throughout the growing period.

1. Components of Soil Fertility:

a. Physical properties such as texture, structure, porosity, and water-holding capacity determine root growth and nutrient movement. Well-structured soils allow better aeration and water infiltration, which support both crops and trees.

b. Chemical properties include soil pH, cation exchange capacity (CEC), and availability of macro- and micronutrients. Soil pH strongly influences nutrient solubility and uptake, while CEC determines the soil's ability to retain nutrients and prevent losses.

c. Biological properties involve soil microorganisms such as bacteria, fungi, and actinomycetes that play a vital role in decomposing organic matter and releasing nutrients in plant-available forms.

2. Nutrient Cycling in Soil: Nutrient dynamics in soil involve several key processes:

a. Mineralization: Conversion of organic nutrients into inorganic forms that plants can absorb.

b. Immobilization: Temporary locking of nutrients in microbial biomass.

c. Nitrification and denitrification: Transformations of nitrogen that can lead to losses in the form of gases such as nitrous oxide (N_2O).

d. Leaching and runoff: Movement of nutrients beyond the root zone or into water bodies.

3. Role of Trees in Nutrient Dynamics: Trees significantly influence soil fertility and nutrient cycling, making them essential components of sustainable land-use systems.

a. Deep nutrient extraction: Tree roots extend deeper than most crops, absorbing nutrients from subsoil layers that are otherwise inaccessible. These nutrients are returned to the topsoil through leaf litter and root turnover, a process often referred to as "nutrient pumping."

b. Litter fall and decomposition: Leaves, twigs, and other biomass from trees decompose and add organic matter to the soil. This not only improves soil structure but also releases nutrients slowly, ensuring sustained availability (Singh *et al.*, 2022).

c. Biological nitrogen fixation: Leguminous trees such as *Acacia* and *Albizia* host symbiotic bacteria that fix atmospheric nitrogen, enriching soil fertility naturally.

d. Reduced nutrient losses: Tree cover reduces soil erosion, runoff, and leaching losses by improving soil structure and protecting the soil surface.

e. Enhanced microbial activity: Tree-based systems create a favourable environment for soil organisms, which in turn accelerate nutrient cycling and improve soil health.

Fertilizers and Greenhouse Gas Emissions

1. Major Greenhouse Gases from Fertilizer Use: Fertilizer application leads to the emission of three major greenhouse gases:

a. Nitrous oxide (N_2O): The most critical GHG associated with fertilizers. It is produced during microbial processes such as nitrification and denitrification in soils. N_2O has a global warming potential nearly 273–298 times higher than CO_2 over a 100-year period (IPCC, 2021).

b. Carbon dioxide (CO_2): Emitted during fertilizer manufacturing (energy-intensive processes like the Haber-Bosch process) and from soil respiration after fertilizer application.

c. Methane (CH_4): Mainly emitted in flooded conditions such as rice paddies, where anaerobic conditions promote methane production.

2. Mechanisms of GHG Emissions in Soil:

a. Nitrification: Conversion of ammonium (NH_4^+) to nitrate (NO_3^-), producing N_2O as a by-product.

b. Denitrification: Reduction of nitrate to nitrogen gases (N_2O and N_2) under anaerobic conditions.

c. Volatilization: Loss of ammonia (NH_3), which can later contribute indirectly to N_2O emissions.

d. Leaching: Movement of nitrate into groundwater, reducing fertilizer efficiency and contributing to indirect emissions.

3. Soil fertility by tree based systems:

Table 1: Strategies to Improve Soil Fertility by incorporating trees:

Strategy	Role of Trees/Agroforestry	Key Outcome	Reference
Integrated Nutrient Management (INM)	Trees contribute leaf litter and root biomass, which enhance organic matter and improve nutrient cycling.	Improves nutrient use efficiency by 15–25% and sustains soil health.	Ladha *et al.*, 2020
Organic Matter Management	Trees continuously add organic matter through litter fall and root turnover, enriching soil carbon.	Increases soil organic carbon and enhances nutrient retention.	Nayak *et al.*, 2014
Agroforestry Systems	Deep-rooted trees recycle nutrients from subsoil layers and leguminous trees fix atmospheric nitrogen.	Increases soil organic carbon by 10–25% and reduces nutrient losses.	Nair, 2012;: Nayak, *et al.*, 2014
Balanced Fertilization	Trees improve nutrient availability and reduce the need for excessive fertilizer inputs.	Enhances fertilizer use efficiency and prevents nutrient imbalance.	Fixen *et al.*, 2015
Biofertilizers	Tree roots support microbial diversity, increasing the effectiveness of bio fertilizers.	Improves nutrient availability and reduces chemical fertilizer dependence.	Singh *et.al.*, 2022
Conservation Agriculture	Tree cover reduces soil erosion, improves moisture retention, and supports biodiversity.	Enhances soil stability and long-term productivity.	Smith *et al.*, 2019
Green Manuring	Trees provide favourable microclimate conditions and support better growth of green manure crops.	Increases nitrogen availability and improves soil structure.	Palm *et al.*, 2001
Improved Fertilizer Technologies	Trees help capture excess nutrients and reduce leaching losses in agroforestry systems.	Reduces nutrient losses and lowers GHG emissions.	Subbarao *et al.*, 2006

Conclusion

Tree-based systems reduce dependence on chemical fertilizers while minimizing greenhouse gas emissions, particularly nitrous oxide. By increasing soil organic carbon and supporting microbial activity, forests and agroforestry systems contribute to long-term soil health and climate resilience. Future strategies should emphasize the integration of suitable forest tree species with site-specific nutrient management and digital technologies to ensure sustainable productivity and environmental protection.

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Post-Harvest Primary Processing and Storage of Pearl Millet (Bajra)

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Dr. Dinesh Rajak[1], Dr. Vishal Kumar[2], Dr. Devendra Kumar[3]
[1&2]Associate Professor and [3]Professor, Processing and Food Engineering, CAE&T, Dr. Rajendra Prasad Central Agricultural University, Pusa, Samastipur, Bihar.

Introduction

Pearl millet (Bajra) is one of the major coarse grain (millet) crops of India, widely cultivated especially in dry and semi-arid regions. This crop is highly important from a nutritional point of view as it is rich in protein, dietary fiber, iron, and other essential minerals. Considering the growing population and the need for nutritional security, the importance of pearl millet is continuously increasing.

Post-harvest management of the crop is equally important as its cultivation. If proper processing and storage are not carried out after harvest, the quality of grains is affected and significant losses may occur due to insects, fungi, and moisture. Therefore, scientific and appropriate techniques must be adopted to preserve grain quality, ensure safe storage, and obtain better market value.

In this context, the topic **"Primary Processing and Storage of Pearl Millet after Harvest"** is very important as it helps farmers reduce post-harvest losses and maximize profit from their produce.

Proper Time of Harvesting of Pearl Millet

Pearl millet should be harvested when the ears are fully matured and grains become hard. Generally, harvesting is suitable when grain moisture is around 18–20%. Delayed harvesting may lead to grain shattering and bird damage. Timely harvesting is very important for good yield and quality.

Indicators of Proper Harvesting Stage

a. Ear heads are fully developed and hardened
b. Grains are hard and shiny
c. Leaves of the plant turn yellow or dry
d. Grain moisture is around 18–20%

Suitable Harvesting Time

a. Usually, pearl millet becomes ready for harvest in 75–90 days after sowing (depending on variety and climate).
b. Harvesting in morning or evening is better to reduce grain shattering.

Benefits of Timely Harvesting

a. Maintains good grain quality
b. Reduces losses due to shattering and birds
c. Minimizes storage losses

Losses Due to Early or Late Harvesting

a. Early harvesting: grains remain immature, reducing weight and quality
b. Late harvesting: grains may shatter and are prone to insect and bird damage

Drying

After harvest, the crop should be properly sun-dried.
a. Spread ear heads in sunlight for 3–5 days
b. Reduce grain moisture to 12–14%
c. Proper drying reduces fungal and insect attack

Importance of Drying

a. Ensures long-term storage safety
b. Prevents fungal and insect infestation
c. Maintains quality and nutritional value

Drying Methods

a. Spread harvested heads in sunlight
b. Turn regularly for uniform drying
c. Use tarpaulin or plastic sheets to avoid soil contact

Safe Moisture Levels

a. Before threshing: 14–15% moisture
b. For storage: 10–12% moisture

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Precautions:

a. Avoid drying during rain or high humidity
b. Cover grains at night to prevent moisture absorption
c. Protect from birds and animals

Threshing

After drying, grains are separated from ear heads using manual, animal, or mechanical methods.

Methods of Threshing

a. Manual threshing (beating or rubbing)
b. Animal threshing (bullocks treading)
c. Machine threshing (thresher)

Precautions

a. Crop should be fully dry
b. Clean and flat surface should be used
c. Damaged grains should be removed

Benefits

a. Saves time and labor
b. Improves grain quality
c. Makes cleaning and storage easier

Cleaning and Grading (Cleaning & Sorting)

After threshing, grains are cleaned to remove dust, husk, stones, and impurities.

Importance:

a. Removes dust, husk, and impurities
b. Reduces storage losses
c. Improves market value

Cleaning Methods:

a. Winnowing (air separation)
b. Sieving (screening)
c. Machine cleaning

Grading:

a. Separation based on size, weight, and quality
b. Improves market price

Benefits:

a. Higher market price
b. Easier processing
c. Uniform storage quality

Primary Processing

After harvesting and cleaning, grains undergo basic processing:

Methods

a. Dehulling (removal of outer husk)
b. Milling (flour making)
c. Roasting
d. Popping (puffed products)

Importance

a. Improves usability and digestibility
b. Enhances taste and shelf life
c. Increases value addition and income

Precautions

a. Grains must be clean and dry
b. Hygienic equipment should be used
c. Avoid excessive heat to prevent nutrient loss

Storage

Proper storage ensures long-term safety of grains.

Requirements

a. Moisture should not exceed 10–12%
b. Store in dry, clean, and ventilated place
c. Use jute bags or airtight containers
d. Regular inspection for insects

Importance

a. Long-term preservation
b. Protection from pests and fungi
c. Maintains nutritional quality

Storage Methods

a. Jute bag storage
b. Airtight containers
c. Warehouse storage

Precautions

a. Maintain proper humidity and temperature
b. Regular monitoring
c. Use safe pest control methods

Insect and Disease Control

Storage pests can cause major damage to grains.

Major Insects

a. Weevils
b. Beetles
c. Moths

Fungal Diseases

a. Occur due to high moisture
b. Cause discoloration and toxin formation

Control Measures

Preventive

a. Proper drying (10–12% moisture)
b. Clean storage environment
c. Separate old and new grains

Natural Methods

a. Neem leaves or powder
b. Ash treatment

Chemical Methods

a. Approved pesticides (careful use)
b. Fumigation under expert supervision

Monitoring

a. Regular inspection
b. Immediate action if infestation is found

Conclusion

Proper primary processing and storage of pearl millet after harvest is essential to maintain grain quality, nutritional value, and market price. By adopting scientific practices such as timely harvesting, proper drying, threshing, cleaning, grading, and safe storage, farmers can reduce post-harvest losses and increase profitability.

In summary, proper post-harvest management not only ensures grain safety but also contributes significantly to increasing farmer income and improving food security.

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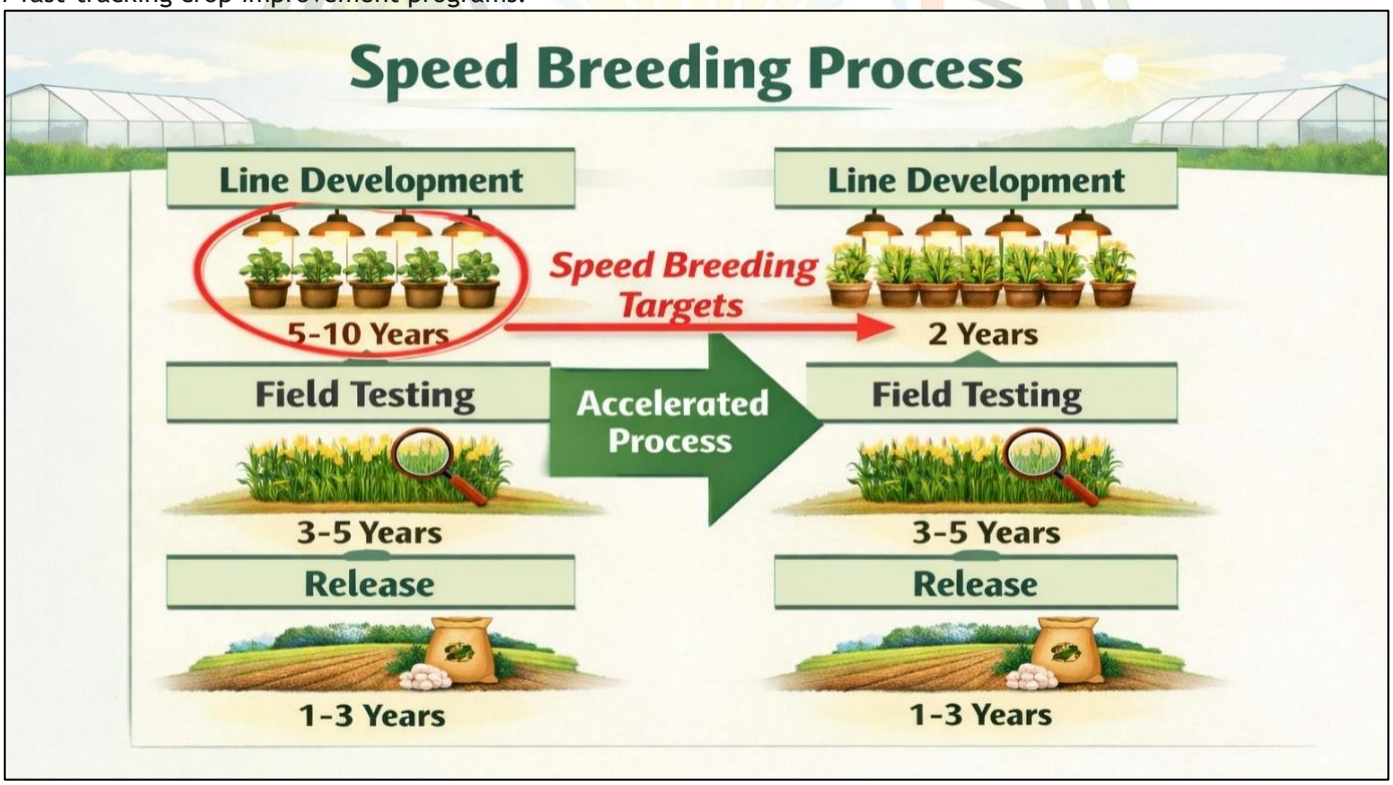
Speed Breeding: Accelerating Genetic Gain

Article ID: 73573

Dushyant Singh[1]
[1]Department of Genetics and Plant breeding, Tilak Dhari Post Graduate College, Jaunpur, Uttar Pradesh, India.

Today's agriculture finds itself at a pivotal crossroad. The worldwide population is expected to surpass 9 billion by the year 2050, leading to a demand for food that is increasing quickly as climate change remains a challenge for crop productivity. While traditional plant breeding has been successful in the past, it is often too slow to address these upcoming challenges. It usually takes 10–15 years of breeding for a new crop variety to be developed, largely because of long generation cycles and time-consuming field investigations. That delay directly constrains the rate of genetic gain — the improvement of beneficial traits like yield, disease resistance and climate resilience.

Speed breeding is a modern crop improvement approach aimed at rapidly advancing plant generations by manipulating environmental conditions such as light, temperature, and photoperiod. The term "speed breeding" was first introduced by researchers at the University of Queensland in the year, 2003, inspired by NASA's work on growing the wheat variety 'USU-Apogee' under continuous light conditions in space (Gopalina *et al.*, 2026). In 2017, researchers at the University of Queensland, Australia, developed one of the first speed-bred spring wheat varieties, 'DS Faraday'. This technique focuses on accelerating flowering and seed development, allowing multiple generations to be completed within a single year. Earlier methods like doubled haploid (DH) production and shuttle breeding helped reduce breeding cycle duration, but speed breeding surpasses them due to its precision, scalability, and compatibility with modern technologies. It can be effectively integrated with advanced tools such as marker-assisted selection (MAS), genomic selection, high-throughput genotyping and phenotyping, and gene editing technologies like CRISPR Cas9, making it a powerful strategy for fast-tracking crop improvement programs.



The most recently developed approach for rapid generation of pure lines is speed breeding. SB minimizes the vegetative period of each generation by creating conditions that promote: (1) accelerated flowering, (2) rapid seed maturation, and (3) overcoming postharvest dormancy to enable successive cultivation cycles. The feasibility of this approach for accelerating growth in long-day crops was first demonstrated in 2018. This groundbreaking study achieved six generations per year for spring wheat, barley, chickpea, and pea, along with four generations annually for rapeseed. In practical terms, pure lines of spring cereals and legumes were obtained within one year, while rapeseed required 1.5 years (Watson *et al.*, 2018). A detailed protocol for replicating these results was published concurrently (Ghosh *et al.*, 2018).

Factors Influencing SB Protocols (Blinkoy *et al.*, 2025)

1. Photoperiod (Day Length): Photoperiod is one of the most critical environmental signals regulating plant development. It determines the transition from vegetative to reproductive stages. Plants are classified into short-day, long-day, and day-neutral types based on their response to day length.

a. Long-day and day-neutral plants: Accelerated flowering is achieved using extended photoperiods, typically 22 hours light and 2 hours dark. A short dark period is important to maintain circadian rhythms and plant health.

b. Short-day plants: Require species-specific shorter photoperiods (e.g., 8/16, 10/14, or 12/12 light/dark cycles). A common strategy is to first grow plants under long days to increase biomass, then shift to short days to induce flowering.

c. Gradual simulation of dawn and dusk can further improve plant quality.

2. Light Sources and Spectral Composition: Light quality influences photosynthesis, morphology, and flowering. Artificial lighting replaces sunlight in controlled environments.

a. Common light sources include LEDs, fluorescent lamps, metal-halide, and sodium lamps.
b. LEDs are preferred due to energy efficiency and ability to control light spectrum.
c. Far-red light accelerates flowering by influencing flowering genes but may cause elongation and reduced yield.
d. Red and blue light promote compact growth, earlier flowering, and better plant structure.
e. Some wavelengths (e.g., UV-A or near-infrared) may slow growth, while green light can improve plant health in some crops.
f. Light spectrum requirements vary among species, so optimization is crop-specific.

3. Light Intensity: Light intensity directly affects photosynthesis and growth rate.

a. Optimal intensity for most crops: 450–500 µmol/m^2/s.
b. Higher intensities (800–1000 µmol/m^2/s) may further accelerate growth in some species.
c. Low intensity delays development, while excessively high intensity can cause photoinhibition, leaf damage, and reduced productivity.
d. Proper balance is essential to maintain plant health and ensure rapid development.

4. Temperature: Temperature regulates all stages of plant development, including germination, flowering, and seed formation.

a. General optimal range: 22–25°C (daytime) for most crops.
b. Warm-season crops may require 28–32°C.
c. Stable temperatures are essential, as fluctuations can cause stress and slow growth.
d. Slightly lower temperatures at night can improve plant performance.
e. Special treatments like cold exposure (vernalization) are necessary for some crops to initiate flowering.

5. Carbon Dioxide (CO_2): CO_2 plays a key role in photosynthesis and biomass production.

a. Elevated CO_2 can enhance growth, yield, and biomass accumulation.
b. Its effect on flowering time is inconsistent—some crops respond positively, while others show no change.
c. More commonly, CO_2 improves plant productivity and reproductive success rather than accelerating development.

6. Vernalization: Vernalization is the exposure to low temperatures required for flowering in certain crops.

a. Essential for winter cereals, biennial crops, and some Brassica species.
b. Traditional vernalization may take several weeks, slowing breeding cycles.
c. Accelerated methods (e.g., treating germinating seeds or embryos) can reduce duration.
d. Effectiveness varies across genotypes, limiting universal application.

7. Mineral Nutrition: Nutrient availability strongly influences plant growth and flowering.

a. Nitrogen (N): Promotes vegetative growth but delays flowering if excessive.
b. Phosphorus (P) and Potassium (K): Promote earlier flowering; both deficiency and excess may induce stress-related early flowering.
c. Micronutrients: Essential for plant health, seed quality, and efficient development.
d. Continuous monitoring is necessary due to rapid growth in speed breeding systems.
e. Nutrient delivery methods (soil vs foliar) affect plant performance.

8. Substrate Volume and Growing Conditions: Physical growing conditions influence plant development rate.

a. High-density planting in small containers induces competition and stress, accelerating flowering.
b. Suitable for rapid breeding methods like single-seed descent.
c. Extremely small containers can limit growth and reduce productivity.
d. Substrate composition (e.g., nutrient-poor media) can also shorten the vegetative phase.

9. Mechanical Tiller Removal: This method is mainly used in cereals.

a. Removal of side tillers focuses growth on the main shoot.
b. Slightly reduces time to maturity and improves uniformity.
c. However, it is labor-intensive and reduces total seed yield, limiting its large-scale use.

10. **Plant Growth Regulators (PGRs):** Growth regulators are used to manipulate plant physiological processes.
    a. Gibberellic acid (GA): Commonly used to break seed dormancy.
    b. Other regulators can:
        i. Reduce plant height (for compact growth)
        ii. Improve pollination and seed set
        iii. Induce flowering or modify sex expression in certain crops
    c. Their use is often crop-specific and targeted to solve particular challenges.
11. **Embryo Culture and Seed Drying:** These methods help reduce generation time by shortening seed maturation.
    a. Embryo culture: Immature embryos are grown in vitro to produce new plants quickly.
        i. Fast but requires specialized equipment and expertise.
    b. Forced drying of immature seeds: Simpler method involving drying seeds before full maturity.
        i. Easier to implement but may reduce germination and productivity.
12. **Overcoming Postharvest Dormancy:** Seed dormancy delays the start of the next generation and must be overcome.
    a. Methods include:
        i. Stratification (cold treatment)
        ii. Scarification (seed coat weakening)
        iii. Heat treatment
        iv. Chemical treatments (e.g., GA, $CaCl_2$)
    b. Immature seeds can sometimes be used directly to bypass dormancy, though they may produce weaker seedlings.
13. **Genetic and Biotechnological Approaches:** Advanced methods enhance speed breeding efficiency.
    a. Introduction of early flowering genes can eliminate the need for vernalization.
    b. Gene expression techniques (e.g., inducing flowering genes) accelerate flowering and fruiting.
    c. These approaches are especially useful for crops with long life cycles or strict environmental requirements.

Conclusion

Accelerated flowering, maturation, and dormancy breaking depend on the combined optimization of multiple parameters, including photoperiod, light quality, temperature, nutrition, and genetic factors. No single factor is universally effective; instead, crop-specific and genotype-specific strategies are required. Integrating these parameters enables efficient speed breeding, allowing rapid generation turnover and improved crop development.

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Jeevamrit: A Key Component of Natural Farming for Sustainable Agriculture

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Indraganti Raja Sri Charan[1], B Maheshwari[2], Rajat Rajput[3], Preeti Kumari[4], Manish Kumar[5]

[1]M. Sc. Scholar Vegetable Science, Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir, Shalimar, Jammu and Kashmir.

[2]Teaching Associate, Department of Soil Science and Agricultural Chemistry, Agricultural College, Karimnagar.

[3]Ph.D. Scholar, Department of Horticulture (Vegetable Science), School of Agricultural Sciences, Nagaland University, Medziphema Campus.

[4]Ph.D. Scholar, Department of Fruit Science, Bihar Agricultural University, Sabour, Bhagalpur, Bihar, India.

[5]Ph.D. Scholar, Department of Horticulture (Fruit Science), School of Agricultural Sciences, (Nagaland University), Medziphema Campus, India.

Abstract

Natural farming is gaining importance as a sustainable alternative to chemical-based agriculture due to its positive effects on soil health, fertility, and long-term productivity. Jeevamrit, a fermented liquid organic formulation, plays a key role in this system by enhancing microbial activity and nutrient availability in the soil. Prepared from cow dung, cow urine, jaggery, pulse flour, soil, and water, it acts as both a biofertilizer and soil conditioner. The microorganisms present in Jeevamrit contribute to nutrient cycling, nitrogen fixation, and decomposition of organic matter. It also improves soil structure, water retention, and plant growth. Additionally, Jeevamrit helps suppress soil-borne diseases and reduces dependence on chemical inputs. Overall, it promotes sustainable agriculture and environmental protection.

Keyword: Jeevamrit, Sustainable Agriculture, biofertilizer, microorganisms.

Introduction

The significance of natural farming practices has been steadily rising as farmers increasingly recognize their advantages in improving soil fertility, maintaining soil health, and ensuring long-term sustainable productivity. Among these practices, the application of Jeevamrit, a liquid organic formulation, has gained considerable attention in organic farming due to its crucial role in enhancing crop growth and yield. Natural farming encompasses a range of techniques aimed at achieving efficient and sustainable crop production, many of which have been innovated and refined by farmers themselves. One such important practice is the use of Jeevamrit, which primarily aims to enrich and stimulate beneficial soil microflora (Sharma *et al.*, 2025).

The Green Revolution was initiated to meet the growing global demand for food and significantly boosted agricultural production worldwide. However, it relied heavily on the extensive use of synthetic fertilizers and pesticides. While this approach resulted in higher crop yields, it also led to serious environmental concerns such as soil degradation, loss of biodiversity, and water contamination (Vibha et al., 2023). In addition, the indiscriminate and unregulated use of chemical fertilizers by farmers has further aggravated these issues, resulting in declining soil health, reduced fertility, and adverse effects on long-term agricultural productivity (Somdutt *et al.*, 2023).

To address these challenges, there has been a shift toward sustainable agricultural practices, including organic and natural farming. Natural farming is largely rooted in traditional Indian agricultural knowledge systems and avoids the use of synthetic inputs. This approach emphasizes the integration of livestock, particularly indigenous cow breeds, as a key component. Its primary objectives are to enhance soil health, restore ecological balance, and minimize the cost of cultivation. A fundamental principle of natural farming is the use of farm-derived inputs such as Bijamrit, Ghanjeevamrit, and especially Jeevamrit. It also highlights the importance of maintaining proper soil moisture and aeration, referred to as Wapsa.

Jeevamrit is a fermented organic formulation prepared from cow dung, cow urine, jaggery, pulse flour, soil and water. The term “Jeevamrit” is derived from two words: “Jeeva,” meaning living organisms, and “Amrit,” meaning nectar, thus signifying it as the “nectar of life.” It plays a significant role in enhancing soil nutrient status and supporting the growth of healthy plants. Rich in beneficial microorganisms, Jeevamrit acts as a reservoir of microbial life that aids in improving soil biological activity. It contributes to the supply of essential nutrients required for plant growth and functions as a catalyst in stimulating natural processes within the soil.

Moreover, Jeevamrit is easy to prepare and can be produced according to the farmer’s needs. As a liquid organic manure, it serves as an excellent source of organic carbon and biomass, along with important micronutrients necessary for crop development. Overall, Jeevamrit functions both as an organic fertilizer and a soil conditioner, prepared from natural ingredients and enriched with beneficial microbial populations.

Jeevamrit is not only utilized as an organic fertilizer but also serves as a bio-starter that introduces beneficial microorganisms, helping to establish a biologically active and healthy soil environment. Its application enhances microbial activity in the soil, thereby improving nutrient availability for crops. It creates favorable conditions for the growth and multiplication of beneficial microbes, which play a crucial role in soil health.

Several scientific studies have demonstrated that the use of Jeevamrit significantly improves soil fertility. It contains a high microbial population that multiplies rapidly, functioning as a soil tonic. These beneficial microorganisms enhance the availability of essential nutrients, supporting better plant growth, development, and overall vigor. In addition, research findings indicate that Jeevamrit also contributes to protecting plants against various diseases by strengthening the soil's biological ecosystem.

Composition and Preparation Methods for Jeevamrit

Jeevamrit is a liquid fermented organic manure prepared from a specific combination of natural and farm-derived ingredients. It essentially functions as a fermented culture, enriched through biological processes. Due to the synergistic action of its components during fermentation, Jeevamrit acts as a bio-enhancer, promoting soil biological activity and improving overall crop performance.

1. Core ingredient: Jeevamrit is commonly prepared using cow dung, cow urine, jaggery, pulse flour, and a small amount of soil (Madrewar *et al.*, 2025). Water acts as the solvent, allowing all these components to be properly mixed and undergo fermentation.

a. Cow dung: It serves as the primary source of beneficial microorganisms, including nitrogen-fixing bacteria and phosphate-solubilizing bacteria (PSB). It also provides organic matter that acts as a substrate for microbial growth.

b. Cow urine: It acts as a source of essential nutrients, particularly nitrogen and potassium. The presence of uric acid supports microbial proliferation and also contributes to plant nutrient uptake.

c. Jaggery: It functions as a carbon source, promoting rapid multiplication and enhancing the metabolic activity of microorganisms during fermentation.

d. Pulse Flour: It provides proteins and amino acids, which help in the growth and multiplication of microbial populations.

e. Soil: A small quantity of soil is added as an inoculum of beneficial microbes. It ensures the introduction of native microbial strains into the mixture, which will later be active in the field.

f. Water: Water acts as a solvent for dissolving and mixing all the ingredients. Generally, about 20–200 liters of water is used for preparing one batch of Jeevamrit.

2. Preparation Process: The preparation of Jeevamrit involves a simple yet well-defined procedure that ensures effective fermentation and the multiplication of beneficial microorganisms.

The standard formulation for the preparation of Jeevamrit is given as follows (Palekar, 2006):

a. Fresh Cow Dung - 10-12 Kg
b. Cow urine - 10-12 Litre
c. Jaggery - 2 Kg
d. Pulse Flour - 2 Kg
e. Water - 200 litre
f. Soil - Approx. 100 gm.

Role of Microorganisms

Microorganisms play a vital role in Jeevamrit, serving as invisible agents that enhance soil health and support plant growth.

Here's how they Contribute

Breakdown of Organic Matter: The microorganisms present in Jeevamrit, including bacteria and fungi, decompose organic matter into humus, thereby releasing essential nutrients. This process improves soil fertility by making these nutrients more readily available for plant uptake.

Fixation of Nitrogen: Jeevamrit also contains nitrogen-fixing bacteria such as *Rhizobium*, which convert atmospheric nitrogen into forms that can be readily utilized by plants. By promoting the growth and activity of these beneficial microbes, Jeevamrit enhances soil nitrogen availability and reduces dependence on chemical fertilizers.

Enhancing Soil Structure: Beneficial microorganisms, including actinomycetes, play an important role in breaking down complex organic compounds such as cellulose. Their activity enhances soil structure and aeration, allowing plant roots to grow more freely and efficiently absorb water and nutrients.

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Suppression of Disease: Microorganisms such as *Trichoderma* and *Bacillus* effectively suppress harmful pathogens by outcompeting them in the soil environment. By establishing a competitive microbial ecosystem, they inhibit the growth and activity of disease-causing fungi, bacteria, and other pests, thereby reducing soil-borne diseases.

Promoting of Plant Growth: Certain microorganisms produce plant growth promoting substances, including hormones such as auxins and cytokinins, which stimulate root development and improve plant vigor. These hormones enhance the plant's ability to withstand stress and support stronger, more resilient growth.

Improving Nutrient Availability: Microorganisms present in Jeevamrit help in solubilizing essential minerals such as phosphorus, potassium, and sulphur, thereby making them more readily available to plants. They mobilize nutrients that are otherwise locked in the soil, ensuring efficient uptake and utilization by crops.

Increased Microbial Diversity: Jeevamrit introduces a wide diversity of microorganisms into the soil, helping to establish a balanced microbial ecosystem. This diversity prevents the dominance of any single group, thereby maintaining a stable and resilient soil environment that supports long-term fertility and minimizes the risk of soil degradation.

Effects of Jeevamrit Microorganisms on Soil and Environmental Health

The application of Jeevamrit in organic farming offers several advantages. These benefits include:

Soil Fertility: Jeevamrit improves soil fertility by integrating organic matter with a rich and diverse microbial community. This combination enhances soil structure, replenishes essential nutrients, and promotes long-term soil health. In contrast to synthetic fertilizers, which may deteriorate soil quality over time, Jeevamrit supports sustainable soil productivity.

Sustainability: By minimizing dependence on chemical fertilizers and pesticides, Jeevamrit encourages sustainable agricultural practices. Soil enriched with beneficial microorganisms becomes naturally more resilient to pests and diseases, thereby reducing the need for chemical inputs.

Sequestration of Soil Carbon: Microorganisms present in Jeevamrit contribute to carbon sequestration in the soil, thereby helping to mitigate climate change. Through the decomposition of organic matter, these microbes facilitate the formation of humus, which stores carbon and enhances soil structure.

Enhanced Crop Productivity

The microbial diversity promoted by Jeevamrit supports the development of strong root systems, enhances nutrient uptake, and encourages healthy plant growth, ultimately leading to increased crop yields. Furthermore, the activity of these microorganisms improves soil water-holding capacity, ensuring that plants receive essential nutrients even under dry conditions.

Environmental Benefits

Jeevamrit promotes ecological balance by supporting a rich and active microbial ecosystem in the soil. It helps reduce soil erosion, prevents the runoff of chemicals into water bodies, and lowers the overall environmental impact of agricultural practices. Additionally, by minimizing the use of inorganic or chemical fertilizers, Jeevamrit contributes to reducing soil and water pollution associated with conventional farming methods.

Conclusion

Jeevamrit is an effective and eco-friendly input in natural farming that significantly enhances soil fertility and crop productivity. Its rich microbial composition improves nutrient availability, soil structure, and plant health. By reducing the use of chemical fertilizers and pesticides, it supports sustainable and environmentally safe agricultural practices. Jeevamrit also contributes to carbon sequestration and ecological balance, helping mitigate environmental degradation. Its low cost and ease of preparation make it highly suitable for farmers, especially smallholders. The use of Jeevamrit strengthens soil biological activity and resilience against stress and diseases. Therefore, it serves as a vital component for achieving sustainable and profitable agriculture in the long run.

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Impact of Inflation on Agricultural Input Costs

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Harkesh Kumar Balai[1], Anshu[2]

[1]Assistant Professor,Faculty of Agriculture, Jagannath University Jaipur (Rajasthan), India-303901.

[2]Student, B.Sc. (Hons.) Agriculture, Faculty of Agriculture, Jagannath University Jaipur (Rajasthan), India-303901.

Abstract

The Indian agricultural sector is currently navigating a complex economic landscape defined by rising cultivation costs and the transformative potential of digital technology. This article examines how global and domestic inflation have directly impacted "Agricultural Inputs," such as fertilizers (DAP and Urea), labor, and hybrid seeds, thereby squeezing the net profit margins of farmers. Through a detailed five-year analysis (2021–2025), the study tracks the steady escalation of input costs and compares these trends against the market price fluctuations of major Kharif and Rabi crops. The findings indicate that while government-mandated Minimum Support Prices (MSP) have increased, they often only serve to keep pace with inflationary pressures. To counter these challenges, the article highlights e-commerce as a strategic intervention. By facilitating market diversification, providing real-time price transparency, and reducing post-harvest losses, digital platforms empower farmers to bypass traditional middlemen and secure better profit margins. Ultimately, the integration of agri-tech and e-commerce represents a vital frontier for maintaining the economic viability of farming in an increasingly expensive environment..

Keywords: gricultural Inflation, Input Costs, E-commerce, Kharif Crops,Minimum Support Price (MSP)

Introduction

The Indian agricultural sector is currently undergoing a period of transition. While global and domestic inflation has pressured the economic condition of farmers by increasing cultivation costs, the digital revolution and e-commerce have opened new doors of opportunity. Inflation directly affects "Agricultural Inputs," thereby reducing the net profit margin at the end of the harvest.

5 Year Detailed Analysis of Agricultural Input Costs

Over the past five years, massive spikes in the rates of basic farming necessities have been observed due to global supply chain disruptions and rising raw material prices.

Table 1: Comparison of Agricultural Input Costs (2021-2025):

Input Item (unit)	DAP (per bag 50kg)	Agri Labour (per day)	Hybrid seeds (per packet)	Urea (per bag 45kg)
2021(Rs)	1200	280	450	266
2022(Rs)	1350	330	485	266
2023(Rs)	1350	380	505	266
2024(Rs)	1450	430	520	280
2025(Rs)	1500	500	540	300
Increase%	6%	15%	5%	3%

Source: Various Govt. Agricultural Statistics (DES) and Market Survey Reports 2021-2025

Market Analysis of Kharif Season

Kharif crops are primarily sown with the Southwest monsoon. The main reason for high input costs in these crops is the heavy use of diesel for irrigation and expensive pesticides to protect against pests during the monsoon.

Table 2: 5-Year Rate Comparison of Kharif Crops (Per Quintal):

Crop name (unit)	Paddy (Rs/q)	Maize (Rs/q)	Cotton (Rs/q)	Arhar (Rs/q)
2021(Rs)	1940	1870	5726	6300
2022(Rs)	2040	1962	6080	6600
2023(Rs)	2183	2090	6620	7000
2024(Rs)	2300	2225	7021	7550
2025(Rs)	2450	2350	7500	8000

Source: Commission for Agricultural Costs and Prices (CACP), MSP Data, and e-NAM (National Agriculture Market) Portal (2021-2025).

Rabi Season Market Analysis

Rabi crops are sown in October-November. These crops see a high demand for fertilizers (specifically DAP), which is directly impacted by international price volatility and domestic inflation

Table 3: 5-Year Rate Comparison of Rabi Crops:

Crop name	Wheat (Rs\q)	Gram (Rs\q)	Barley (Rs\q)	Lentil (Rs\q)
2021	2015	5230	1635	5500
2022	2125	5335	1735	6000
2023	2275	5440	1850	6425
2024	2400	5650	1950	6700

Source: Indian Council of Agricultural Research (ICAR) and Ministry of Agriculture, Farmers Welfare, Govt of India (2021-2025)

E-Commerce: A Strategic Solution to Rising Costs

E-Market Diversification: E-commerce allows farmers to bypass local middlemen who often take a 15–20% commission. By selling directly to consumers or bulk retailers online, farmers can absorb the rise in input costs through higher selling prices

Information Transparency: Digital tools provide real-time price discovery. This prevents farmers from being forced into "distress sales" during periods of high inflation.

Reduced Post-Harvest Loss: Advanced logistics and cold-chain management provided by e-commerce platforms ensure that more produce reaches the market in prime condition, maximizing revenue per acre.

Input Access: Many platforms now deliver high-quality seeds and fertilizers directly to farmers at competitive rates, helping to lower the initial "Input Cost" burden

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Patharchatta Plant: A Natural Remedy Growing in Your Backyard

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Prachi Kumari Singh[1], Amit Singh[2]
[1]B. Sc Ag 3rd year students at Shivalik College of Engineering, Dehradun, 248197.
[2]Assistant Professor, Shivalik College of Engineering, Dehradun, 248197.

Introduction

Patharchatta is a succulent medicinal plant widely valued in traditional herbal systems. It belongs to the species *Kalanchoe pinnata*, a member of the Crassulaceae family. Patharchatta (*Kalanchoe pinnata*) is believed to have originated in Madagascar.It grows well in tropical and subtropical climates. It is commonly found in states such as Uttarakhand, Uttar Pradesh, West Bengal, Maharashtra, Kerala, and Tamil Nadu. The plant thrives in warm climates with moderate rainfall and is well adapted to grow in a variety of conditions, including rocky soils, wastelands, and household gardens.

The plant is hardy, drought-tolerant, and requires minimal care, which contributes to its widespread cultivation. Patharchatta is especially valued for its leaves, which are rich in bioactive compounds such as flavonoids, alkaloids, and organic acids. Patharchatta (*Kalanchoe pinnata*) commonly referred to as stonebreaker,life plant , air plant, cathedral bells,and Panfuti or Patharchatta.



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Botanical Description

The plant has thick, fleshy leaves with toothed margins that have the remarkable ability to produce new plantlets along their margins, making it highly adaptable and easy to propagate. Its stem is soft, green, and succulent, helping in water storage. The flowers are tubular, bell-shaped, and usually greenish to pink in color, hanging in clusters.

Patharchatta is a perennial herb that grows upright.Its life cycle is continuous, as it does not complete its growth in a single season. Instead, it grows year-round in favorable conditions, with periods of active growth and flowering. It reproduces both by seeds and leaf buds. Its ability to grow new plants from leaves makes it easy to spread and maintain.

Phytochemical Composition

Patharchatta (*Kalanchoe pinnata*) contains a wide range of naturally occurring compounds. Key bioactive groups present in the plant flavonoids such as quercetin and kaempferol, phenolic compounds and tannins ,alkaloids and a distinctive group of compounds called bufadienolides, including bryophyllin A and B. In addition, the plant contains triterpenoids and steroids.

Patharchatta (*Kalanchoe pinnata*) leaves contain several essential nutrients in moderate amounts. On a fresh weight basis, they provide approximately 20–35 mg of vitamin C per 100 g, which supports immune function. The mineral content includes about80–120 mg of calcium and250–350 mg of potassium per 100 g, contributing to bone health and electrolyte balance. In addition, the leaves contain 1–2 g of protein and3–6 g of carbohydrates per 100 g, supplying small amounts of energy and structural nutrients. Organic acids are also present in trace to moderate levels, aiding in metabolic activities.

Patharchatta (*Kalanchoe pinnata*) is widely valued for its therapeutic properties and has been used in traditional medicine for treating various health conditions. Its effectiveness is mainly due to the presence of bioactive compounds that exhibit multiple biological activities.

Traditional and Ethnomedicinal Uses

The plant shows strong anti-inflammatory effects, helping to reduce swelling, pain, and irritation. It is often used in the treatment of joint pain, skin inflammation, and minor injuries. Patharchatta possesses antimicrobial activity against a range of bacteria and fungi. This property makes it useful in preventing infections and supporting the treatment of wounds and skin diseases. The leaves of the plant are commonly applied externally to promote faster healing of cuts, burns, and wounds. Its astringent and soothing properties help in tissue repair and reduce the risk of infection. The plant is also a good source of antioxidants, which protect the body from oxidative stress and cellular damage, thereby supporting overall health and disease prevention. It acts as a natural diuretic, helping in the removal of excess fluids and supporting kidney function, which can be beneficial in managing urinary disorders and kidney stones. The presence of organic acids and other active compounds also contributes to improved digestion and may assist in regulating blood sugar levels.

Value Addition and Processing

Patharchatta (*Kalanchoe pinnata*) can be effectively processed into various value-added products to enhance its usability and market potential. Fresh leaves are commonly used to prepare juice by crushing and filtering, which is applied in traditional remedies. Extract is obtained by boiling or using solvents to concentrate its active compounds, making it more potent and suitable for medicinal formulations. The leaves can also be shade-dried and ground into powder, which has a longer shelf life and can be used in capsules, teas, or topical applications. In addition, Patharchatta is used in the preparation of herbal products such as ointments, creams, gels, and syrups for treating wounds, skin problems, and other health conditions. These processing methods not only improve storage and effectiveness but also create opportunities for small-scale herbal product development and income generation.

Economic Importance

Patharchatta (*Kalanchoe pinnata*) holds significant economic importance due to its increasing demand in traditional medicine and herbal product markets. The growing preference for natural and plant-based remedies has boosted its market demand, especially for products like herbal juices, powders, extracts, and topical formulations used in treating kidney stones, wounds, and skin disorders. In the herbal industry, Patharchatta has strong potential as it is widely used in Ayurvedic and folk medicine, and can be incorporated into various value-added products such as syrups, capsules, creams, and nutraceuticals. Its easy cultivation, low maintenance, and ability to grow in diverse climatic conditions make it a suitable crop for large-scale production.

For farmers, Patharchatta offers promising income opportunities as it requires minimal investment and can be harvested multiple times a year. It can be sold as fresh leaves or processed into higher-value products like powders and extracts to increase profit margins. Additionally, with proper training, farmers can engage in small-scale processing and direct marketing of herbal products, creating opportunities for self-employment and rural entrepreneurship. The rising interest in medicinal plants at both national and international levels further enhances its potential as a profitable and sustainable crop.

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Makoy: From Weed to Health

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Prachi Kumari Singh[1], Amit Singh[2]
[1]B. Sc Ag 3rd year students at Shivalik College of Engineering, Dehradun, 248197.
[2]Assistant Professor, Shivalik College of Engineering, Dehradun, 248197.

Introduction

Makoy is scientifically known as *Solanum nigrum* and belongs to the family Solanaceae. It is believed to have originated in parts of Europe and Asia, though it is now widely distributed across tropical and subtropical regions of the world. Makoy is commonly known as Black Nightshade in English. In India, it is called Makoy (Hindi), Kakamachi (Sanskrit), and Manathakkali (Tamil). It is an annual herbaceous plant. It is a small plant (30–60 cm tall) with soft green stems, simple ovate leaves, and small white flowers. The fruits are round berries that turn black when ripe. It grows naturally in waste lands, roadsides, and cultivated fields, showing high adaptability. It thrives in disturbed soils and can grow both as a weed and as a cultivated medicinal plant. It is propagated by seeds and usually sown during the Kharif season,

It grows well in tropical and subtropical climates with temperatures between 20–35°C and moderate rainfall. Well-drained loamy or sandy loam soil with pH 6.0–7.5 is ideal. It is widely distributed and cultivated across India, especially in states like Uttar Pradesh, Bihar, West Bengal, Tamil Nadu, and Madhya Pradesh.



Phytochemical Compostion

There are several important bioactive compounds found in makoy. It contains alkaloids such as solanine, solamargine, and solasonine, which are known for their therapeutic properties. In addition, glycoalkaloids contribute to its anti-inflammatory and anticancer potential. The plant is also rich in flavonoids and phenolic compounds, which act as strong antioxidants and help protect the body from cellular damage. Other constituents like saponins and tannins provide antimicrobial and immune-boosting effects. Makoy also contains essential vitamins such as vitamin A and vitamin C, along with minerals like iron and calcium.

Nutritive Value

Makoy leaves are rich in essential nutrients and provide significant health benefits. Per 100 g of fresh leaves, they contain approximately 70–85% moisture, 5–7 g carbohydrates, 3–5 g protein, and 1–2 g fiber. They are also a good source of vitamins, especially vitamin A (around 5,000–7,000 IU)andvitamin C (20–40 mg), which support immunity and vision. In terms of minerals, Makoy contains about 200–300 mg calcium, 5–10 mg iron, and 50–70 mg phosphorus per 100 g. Additionally, the presence of antioxidants and phenolic compounds enhances its nutritional and health value. These nutrients make Makoy a highly beneficial leafy vegetable for maintaining overall health.

Uses

The plant Solanum nigrum (Makoy) has been widely used in traditional medicine systems like Ayurveda and folk healing. Different parts of the plant were used to treat various ailments. The leaves and fruits were commonly used for liver disorders, including jaundice, as they are believed to have hepatoprotective properties. A paste of the leaves was applied externally to treat skin diseases, wounds, ulcers, and inflammation. The plant was also used to reduce fever and pain due to its cooling and anti-inflammatory effects. In many regions, Makoy was used to improve digestion and relieve constipation. Additionally, it was given in small quantities to manage respiratory problems like cough and asthma. In South India, the ripe berries and leaves were even consumed as a nutritious leafy vegetable to promote overall health. It is also widely used in the preparation of herbal formulations for liver protection, especially in treating conditions like hepatitis and fatty liver. Its extracts are used for their anti-inflammatory and antioxidant properties, helping to reduce oxidative stress and chronic inflammation. Modern studies have shown that Makoy possesses anticancer potential, as certain compounds like solamargine help inhibit the growth of cancer cells. Additionally, In the pharmaceutical and nutraceutical industries, Makoy is being explored for making capsules, syrups, and plant-based supplements, highlighting its growing role in modern healthcare systems.

Economic Importance

The demand for Solanum nigrum is increasing due to the growing popularity of herbal medicines and natural products. The overall demand for medicinal plants is rising rapidly (about 15–25% annually) due to increased health awareness and preference for herbal remedies. There is also a gap between demand and supply, which creates good market opportunities for cultivation. With rising awareness about Ayurveda and plant-based treatments, the demand for Makoy in pharmaceutical and nutraceutical industries is steadily increasing.

It can be processed into various value-added products such as powders, extracts, syrups, capsules, and herbal formulations, which significantly enhance its market value compared to raw plant material. Makoy also has good export potential, as it is supplied to countries like the USA, UAE, and European nations in the form of dried material and extracts. The plant can be processed into dried vegetable forms to increase its shelf life and usability. In rural areas, Makoy is sometimes used as fodder for livestock. Additionally, the berries have applications in producing natural dyes and are used in small-scale food preparations.

Sustainability and Livelihood

Solanum nigrum (Makoy) supports sustainable agriculture as it grows easily in poor soils with minimal inputs. It fits well in organic and mixed farming systems and helps maintain soil health and biodiversity.

Cultivation of Makoy offers promising livelihood opportunities, especially for small and marginal farmers. Since it requires minimal investment and care, it can be grown alongside other crops to generate additional income. Farmers can earn more by selling not only the raw plant material but also processed products such as dried leaves and powders. The increasing demand for herbal and natural products in markets further enhances its economic potential, making Makoy a viable option for rural employment and income generation.

Small-Scale Business Ideas Grounded on Makoy Products

Solanum nigrum (Makoy) offers good opportunities for small-scale entrepreneurship due to its medicinal and nutritional value. Farmers and entrepreneurs can start businesses by preparing dried leaves, herbal powders, and plant extractsfor sale in local markets. Production ofherbal juices, syrups, and capsules can also induce income with proper processing and packaging. Additionally, Makoy can be sold as a fresh or dried vegetable in regional markets. Small units can also focus on value-added products like herbal teas and skin care preparations. With low investment and increasing demand for herbal products, Makoy-based enterprises can provide sustainable income and rural employment.

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Subsidised Private Cost vs Market Price of Paddy: What Should Farmers Know?

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Dr. Sravanthi Kolla[1]
[1]Assistant Professor, Dept. of Agricultural Economics, Agricultural College, Palem.

Paddy cultivation continues to dominate the agricultural landscape of India, particularly in irrigated regions such as Telangana and Andhra Pradesh. Supported by Minimum Support Price (MSP), input subsidies, and procurement systems, paddy is often perceived by farmers as a safe and profitable crop. However, this perception is largely based on a comparison between the **market price (MSP)** and the **subsidised private cost**, rather than the actual economic cost of production. With updated data for 2026–27, this distinction becomes even more important for understanding the real profitability and sustainability of paddy cultivation.

As per recent government data, the MSP for paddy (common variety) reached about **₹2,369 per quintal in 2025-26** and continues to remain in the range of **₹2,300-2,400 per quintal for 2026-27 expectations**. At the same time, the **all-India weighted average cost of production (C2 proxy trends)** has also been rising steadily, reaching around **₹1,579 per quintal in 2025-26**, compared to ₹1,293 in 2021–22. This indicates a continuous increase in production costs due to rising input prices, labour wages, and irrigation expenses.

However, farmers at the field level do not incur the full cost reflected in these estimates. Instead, they operate under **subsidised private costs**, which significantly reduce their out-of-pocket expenditure. Field-based estimates in Telangana and similar regions suggest that farmers often perceive their cost of cultivation in the range of **₹1,400–1,700 per quintal (A2+FL basis)**, depending on irrigation source and input use. When compared with MSP of around ₹2,300–2,400, this creates a visible margin of ₹600–800 per quintal, leading to the belief that paddy is highly profitable.

The key reason for this gap is the extensive system of **government subsidies** embedded in agriculture. In 2026–27, the Government of India has allocated **₹63,500 crore under PM-KISAN alone**, providing ₹6,000 per year to farmers as direct income support. () In addition, large implicit subsidies continue in the form of:

a. **Fertilizer subsidies**, which have historically exceeded ₹1.5–1.7 lakh crore annually
b. **Free or subsidised electricity** for irrigation (major burden on state budgets)
c. **Irrigation infrastructure subsidies** (canals, lift irrigation projects)
d. **Interest subvention on crop loans**, with ₹22,600 crore allocation in 2026–27 ()

These subsidies significantly reduce the **private cost actually paid by farmers**, even though the real economic cost remains high. For example, the actual cost of electricity for groundwater pumping may be ₹5–7 per unit, but farmers often pay nothing. Similarly, fertilizers like urea are sold at highly subsidised prices, masking their true cost. If these subsidies were removed, the cost of cultivation could increase by **₹400–700 per quintal or more**, depending on input intensity and irrigation method.

This leads to a critical economic insight: **subsidies reduce private cost but do not reduce real cost—they merely shift the burden to the government and society**. As a result, when farmers compare subsidised private cost with MSP, they observe an artificial profit margin. This creates an **illusion of profitability**, where farming appears viable only because a portion of the cost is hidden.

Another important dimension is the **regional variation in cost of cultivation**. In canal-irrigated areas, costs may remain relatively moderate. However, in regions dependent on **borewells and lift irrigation**, costs are significantly higher. Irrigation alone can account for **20–30% of total cost**, and in the absence of free electricity, this share would increase further. Therefore, the gap between subsidised private cost and actual economic cost is much larger in such regions.

The implications of this distorted cost-price relationship are significant. First, it encourages **continued expansion of paddy cultivation**, even in areas where it may not be economically efficient or ecologically suitable. Second, it leads to **overuse of resources**, particularly groundwater and fertilizers, because their prices are artificially low. India already uses **3,000–5,000 litres of water to produce one kilogram of rice**, placing enormous pressure on water resources. Third, it creates a **fiscal burden on the government**, as sustaining high levels of subsidies year after year requires substantial public expenditure.

Moreover, even within private cost calculations, farmers often ignore important components such as **family labour and owned land value**. If family labour is valued at prevailing wage rates (₹300–500 per day) and land rent (₹20,000–40,000 per acre annually) is included, the cost of cultivation increases significantly. This further reduces the real margin between cost and market price, indicating that profitability is much lower than perceived.

From a policy perspective, the 2026–27 scenario highlights the need for a gradual shift in strategy. While MSP continues to provide income security, and subsidies support farmers in the short run, there is a growing need to move toward **efficient and targeted support systems**. This includes promoting:

a. Water-saving technologies such as **Direct Seeded Rice (DSR)**
b. Crop diversification toward pulses, oilseeds, and millets
c. Rational use of fertilizers through nutrient-based management
d. Solar irrigation and energy-efficient pumps.

For farmers, the most important takeaway is the need to understand the difference between **subsidised private cost and actual economic cost**. Relying only on visible expenses can lead to incorrect conclusions about profitability. Maintaining simple farm records, valuing family labour, and considering the true cost of inputs can help in better decision-making. Diversification and efficient resource use can improve long-term income stability.

In conclusion, the updated 2026–27 data clearly shows that while MSP for paddy is around ₹2,300–2,400 per quintal and appears remunerative, the actual cost of cultivation is much higher when subsidies are accounted for. The apparent profit margin is largely due to subsidised private costs, which mask the real economic picture. Recognizing this gap is essential for ensuring that paddy cultivation remains not only profitable for farmers but also sustainable for the economy and the environment in the long run.

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LICHENS: Nature's Ultimate Partnership

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Moola Suma Sree[1], Jonnada Likhita[2], Yaddanapudi Vinay[2], Anjali[3]
[1]Rajmata Vijayaraje Scindia Krishi Vishwa Vidyalaya, Gwalior, M.P., India.
[2]Rani Lakshmi Bai Central Agricultural University, Jhansi, U.P., India.
[3]ICAR-National Research Institute for Integrated Pest Management, New Delhi, India.

Introduction

Have you ever noticed crusty green, grey or yellow patches on rocks, trees or old walls and wondered what they are? They aren't parasites or diseases, or organisms that suck nutrients from the tree. These are **'Lichens'.** They survive in some of the harshest environments from icy arctic tundra's to scorching deserts making them champions of resilience.

What Exactly are Lichens?

They are not a single organism but a symbiotic relationship between two different life forms namely **fungi** (mycobiont, which builds the structure) and **algae** (photobiont, which provides nutrients). Lichens are highly adaptable and omnipresent. Their ability to withstand extremities makes them pioneers in colonizing even barren land.

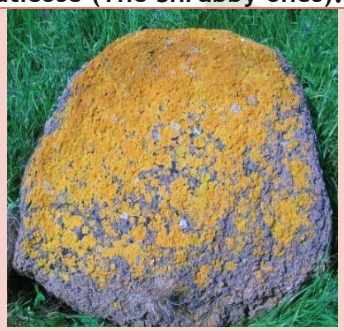
Some of the examples include: *Parmelia*, *Usnea* (Old man's beard), Reindeer lichen, *Lecanora* etc.

Types of Lichens

1. Crustose (The Crusty ones): They form a thin, hard crust that looks like someone splashed green, yellow or grey paint onto a rock or a tree.

2. Foliose (The Leafy ones): They look like ruffled leaves hugging the bark.

3. Fruticose (The Shrubby ones): They look like tiny bushes or long pale beard hanging from the tree.



(a)



(b)



(c)

Why are Lichens Important?

1. Nature's air quality monitors: Lichens are highly sensitive to air pollution, specifically to sulphur dioxide and heavy metals. Their presence indicates clean and healthy air. Because of this, scientists use lichens as bioindicators of environmental health.

2. Soil formation: They secrete mild acids that slowly breaks down rocks into tiny particles thereby paving the way for the growth of other plants

3. Food and habitat: Many animals depend on lichens like Reindeer and Caribou during winter for food, as a nest for birds, and used by invertebrates as a microhabitat.

4. Medicinal and economic uses: They've long been traditionally used as antibiotics and antiseptics, dyes and perfumes, *Roccella* spp. is used to produce a litmus, a natural pH indicator etc.

Conclusion

Lichens continue to surprise scientists with their adaptance and ecological significance highlighting their importance in both biodiversity and space research. Researchers from **MACS-Angharkar Research Institute, Pune** discovered a new species called *'Allographa effusosoredica'* in the Western Ghats which demonstrates how India developed its capability to conduct biodiversity research. This lichen exhibits distinct morphological and chemical properties which include the rare 'norstictic acid 'which was identified through traditional taxonomy methods and modern molecular techniques. Equally fascinating is the **'The Mojave Desert lichens'** which have developed the ability to endure and reproduce extreme solar radiations which scientists compare to radiation found on Earth like planets located in faraway solar

systems. Modern Research continues to uncover new dimensions of their biology and potential applications. So, the next time you notice a patch of lichen on a rock or tree, take a moment to appreciate this tiny yet powerful symbol of resilience and harmony. They remind us that collaboration and adaptability are key to ultimate survival.



-Nature's most delicate lace, spun only where wind breathes clean

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Fungal Frontiers: A Comprehensive Exploration of Mycoremediation, and the Global Potential of Fungi in Biotechnology and Health

Article ID: 73580

Ravi Raunak Barnwal[1], Shubham Saurabh[1], Ashutosh Kumar[1], Sovan Dutta[1], Samir Biswas[1], Shrvan Kumar[1]

[1]Rajiv Gandhi South Campus, Banaras Hindu University.

Abstracts

Mycoremediation is a branch of bioremediation that uses fungi—especially mushrooms—to degrade, transform, or remove environmental pollutants. Fungi achieve this through **biodegradation** (enzymatic breakdown of toxins), **bioconversion** (turning waste into useful biomass), and **biosorption** (binding pollutants to cell walls). The most effective fungal enzymes for pesticide degradation are ligninolytic enzymes, primarily secreted by white-rot fungi like *Phanerochaete chrysosporium* and *Pleurotus ostreatus*. These extracellular enzymes include laccases (LAC), manganese peroxidases (MnP), and lignin peroxidases (LiP). Their enzymes can decompose complex compounds like pesticides, dyes, and hydrocarbons, making them valuable for restoring contaminated soils and water. Marine fungi, though underexplored, are highly adaptable and produce diverse bioactive compounds with antibacterial, antiviral, and anticancer potential. Advances in genomics and metabolomics are accelerating their discovery for biotechnology. Mushrooms also offer nutritional and medicinal benefits, containing proteins, vitamins, and bioactive compounds like **ß-glucans**, which support immunity and help manage obesity and diabetes. Applications include **mycofiltration** for water purification and symbiotic interactions with plants to enhance phytoremediation. While effective, safety concerns such as toxin accumulation require careful monitoring. Overall, fungi hold significant promise for environmental cleanup, sustainable agriculture, and medical innovation, though scaling and field application remain key challenges.

Keywords: Mycoremediation, Biodegradation, Bioconversion, Biosorption, ß-glucans, laccase, LAC, MnP and LiP.

Introduction

Mycoremediation is a specialized branch of bioremediation that specifically employs fungi, particularly mushrooms, to sequester, degrade, or neutralise environmental pollutants. The term was originally coined by Paul Stamets and refers to the process of cleaning or correcting contaminated sites using various fungal classifications. This innovative technology harnesses the unique metabolic capabilities of macrofungi to transform ecological pollutants into less hazardous forms with minimal requirements for external energy, chemicals, or time. Fungi are ubiquitous organisms widely distributed across both terrestrial and marine ecosystems, where they serve as key players in nutrient recycling and energy flow. In terrestrial environments, they are vital allies in the quest for sustainability, converting wood and decaying matter into humus, which enhances soil health and biodiversity. Within the marine realm, fungi play a crucial role in mediating the cycling of dissolved organic matter, though they have been historically neglected compared to their terrestrial counterparts.

Mechanisms of Pollutant Removal

Biodegradation and Bioconversion Mushrooms, primarily belonging to the **Basidiomycetes** group, utilize three primary strategies to recover polluted environments: **biodegradation**, **bioconversion**, and **biosorption**. **Biodegradation** describes the complete mineralization of complex organic molecules into simpler inorganic constituents such as carbon dioxide, water, and nitrates. This process is largely driven by the secretion of powerful **extracellular enzymes**, including **ligninolytic enzymes** like **laccases**, **manganese peroxidases**, and **lignin peroxidases**. These enzymes are non-specific and are naturally produced to break down lignin and cellulose in plant fibers, but they are equally capable of oxidizing a wide spectrum of **xenobiotics**, including pesticides, synthetic dyes, and polycyclic aromatic hydrocarbons (PAHs). **Bioconversion** focuses on the transformation of industrial or agro-industrial waste into useful products, such as protein-rich fungal biomass or fruiting bodies. This dual benefit allows for the mitigation of waste accumulation while simultaneously addressing global food shortages.

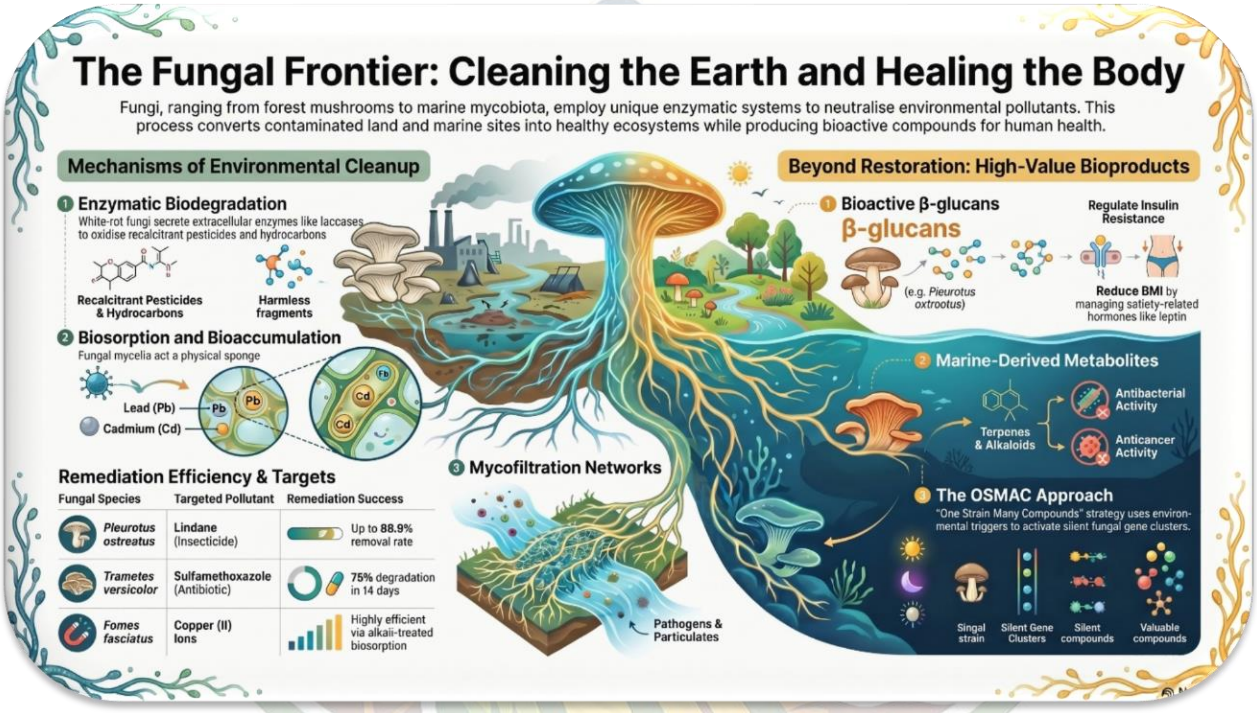
Mechanisms of Pollutant Removal

Biosorption and Bioaccumulation; The second critical method for removing toxicants is **biosorption**, a metabolism-independent process where pollutants bind to the fungal biomass. The fungal cell wall—composed of **chitin**, **glucans**, and proteins—contains various functional groups like polar groups of amino acids and lipids that facilitate the sequestering of metallic ions through **ion exchange**, surface complexation, and microprecipitation. Unlike living cells, **dead fungal biomass** can often be used for biosorption, as it is not sensitive to toxicant concentrations or adverse operating conditions such as extreme pH and temperature. If live fungal cells are present, the process may be followed by **bioaccumulation**, where pollutants are actively transported across the cell membrane and partitioned into

intracellular components. This ability to accumulate heavy metals in the fruiting bodies makes mushrooms effective tools for land restoration, though it can render the resulting mushrooms unsafe for human consumption if the absorbed levels are too high.

Restoring Contaminated Agricultural Land

Agricultural soils are frequently contaminated by **pesticides**, herbicides, and heavy metals, which pose significant risks to human health, including neurological damage. Mycoremediation offers a sustainable solution for these challenges. For instance, applying the fungus *Fomitopsis pinicola* has been shown to degrade **DDT** insecticides by 61%, while *Aspergillus* species are used in **bioaugmentation** to restore soil contaminated with pyrethroid pesticides. Additionally, species like *Lentinula edodes* have been used to improve biopurification systems for wastewater contaminated with pesticides like **pendimethalin**. The success of these efforts is often measured by the reduction of contaminants and the subsequent improvement of soil health markers, such as increased microbial activity and nutrient levels. Furthermore, **spent mushroom substrate (SMS)**—the nutrient-dense byproduct of cultivation—can be used as a soil conditioner or biochar feedstock, further promoting sustainable crop production.



Marine Fungi: The Last Frontier of Biodiversity

While terrestrial fungi are well-studied, **marine fungi** represent an "exotic" and historically underutilized group that may include up to 1 million undiscovered species. Marine fungi are defined as any fungi capable of growing or sporulating in marine environments, forming symbiotic relationships with marine organisms, or being metabolically active in saltwater. These organisms are found in diverse habitats, including **mangroves**, **coral reefs**, seagrass, sponges, and even deep-sea hydrothermal vents. Fungi in the sea face extreme challenges, such as **high salinity**, low temperatures, and extreme hydrostatic pressure. To survive, they have developed molecular adaptations, such as the **high-osmolarity-glycerol (HOG)** signaling pathway, which regulates salt efflux and osmotic stress. Morphological adaptations, such as the development of specialized appendages on spores or the use of **zoospores** for dispersal in water, also contribute to their success in aquatic environments.

Marine Biotechnology and Natural Product Discovery

Marine fungi are a prolific source of **secondary metabolites**, including **alkaloids**, **polyketides**, and **peptides**, which are produced for defense, competition, and communication. More than 3,500 such metabolites have been reported, showing potent **antibacterial**, **antiviral**, and **anticancer** activities. One notable example is **Plinabulin**, a compound isolated from a marine *Aspergillus* species that is currently in late-stage clinical trials for anticancer therapy. The discovery of these natural products is being accelerated by **omics** technologies; **genomics** reveals "silent" biosynthetic gene clusters (BGCs) that may be activated under specific conditions, while **metabolomics** allows for the identification and quantification of complex metabolic profiles. Approaches such as **OSMAC** (One Strain Many Compounds) are used to "awaken" these silent genes by altering cultivation parameters or using chemical elicitors.

The Nutritional and Medicinal Value of Mushrooms

Beyond environmental remediation, mushrooms are recognized as a "best meat substitute" due to their high **protein** content, essential amino acids, and lack of cholesterol. They are rich in minerals like potassium and phosphorus, as well as vitamins B, C, D, and K. Mushrooms also produce various **bioactive compounds** with significant therapeutic potential, including **polysaccharides**, **sterols**, and **peptidoglycans**. These compounds exhibit a wide range of medicinal properties, such as being **antitumor**, **immunomodulatory**, and **antioxidant**. For example, compounds like **ganoderic acid** from *Ganoderma lucidum* show antimicrobial properties, while **velutin** from *Flammulina velutipes* has antiviral effects against HIV.

Role of Mushroom-Based ß-Glucans in Disease Management

Specific research has focused on **-glucans** derived from mushrooms for managing metabolic and immune-related disorders:

1. Obesity Management: ß-glucans can influence peptide hormones like **leptin** and **ghrelin**, which regulate food intake and energy consumption. They have been shown to reduce **triglycerides**, **Low-density lipoprotein (LDL)**, and overall **Body Mass Index (BMI)**.

2. Diabetes Management: In cases of Type-II diabetes, these compounds can help lower blood glucose levels and reduce **insulin resistance** while potentially improving pancreatic beta-cell function.

3. Immunomodulation: ß-glucans act as productive immunomodulators by binding to receptors on **leukocytes**. This stimulates white blood cells like **macrophages** and neutrophils to enhance phagocytosis and release inflammatory cytokines against pathogens.

Mycofiltration and Rhizosphere Interactions

A specialized application of mycoremediation is **mycofiltration**, which involves using networks of fungal mycelium to clean infected water streams. Dense hyphal mats act as physical filters, trapping particulates and microorganisms while chemically binding pollutants like heavy metals, nitrogen, and phosphorus. In the soil, fungi interact with the **rhizosphere** of plants, often forming **syntrophic** partnerships with bacteria. Fungal breakdown products can activate bacterial degraders, leading to more efficient sequential degradation of complex contaminants. Additionally, **arbuscular mycorrhizal fungi (AMF)** improve plant health under pollutant stress, enabling more effective **phytoremediation**.

Success Stories

Case Studies in Mycoremediation**;** The efficacy of mycoremediation is documented through several key case studies:

1. Dual Success (Lindane and Lead): A study using *Pleurotus ostreatus* (Oyster mushroom) achieved an 88.9% removal rate of the insecticide **Lindane** from soil, while the mushroom's fruiting bodies simultaneously bioaccumulated heavy metal **Lead** more effectively than comparison plants.

2. Petroleum Spills: The white-rot fungus *Lentinus subnudus* has proven highly effective at breaking down **petroleum hydrocarbons** and PAHs in soil from oil spill sites, converting complex oil molecules into innocuous ones within 12 weeks.

3. Co-contamination: *Trametes versicolor* (Turkey Tail) was found to simultaneously decompose the herbicide **Atrazine** and the antibiotic **Sulfamethoxazole**, achieving 75% degradation in just 14 days due to its high secretion of the enzyme laccase.

Safety Aspects and the Ames Test

A critical consideration in mycoremediation is the safety of mushrooms grown on waste. While fungi can degrade many organic pollutants, making the fruiting bodies safe, the process of **biosorption** can lead to the accumulation of toxic metals and genotoxic compounds. **Genotoxicity**—the ability of pollutants to cause genetic damage—is often assessed using the **Ames test**. Research has shown that genotoxicity in mushrooms is highly species-dependent; for example, *Pleurotus florida* grown on industrial waste was found to be non-mutagenic, whereas *Pleurotus citrinopileatus* cultivated under identical conditions retained genotoxic properties. Therefore, rigorous toxicity assessments are mandatory before mushrooms or biomass from remediation projects can be utilized as food or animal feed.

Future Prospects and Challenges

Replicating laboratory successes in real-world agricultural soils remains a challenge due to the presence of complex, insoluble pollutant mixtures and varying environmental conditions. The future of mycoremediation lies in **genetic engineering** to create transgenic mushrooms with enhanced tolerance and higher pollutant-removal capacities. There is also a significant need to explore "unculturable" fungal species—the "dark matter" of the fungal kingdom—through culture-independent sequencing and genome-wide analysis. Expanding the availability of marine fungal genomes in public databases will also be crucial for the discovery of novel **biosynthetic gene clusters** and biotechnological applications.

Furthermore, understanding the impact of **climate change** on marine and terrestrial fungal community structures is essential for long-term conservation and management strategies.

Conclusion

Fungi represent a powerful and versatile toolkit for addressing the dual global challenges of environmental pollution and sustainable food production. From the deep-sea sediments to contaminated agricultural fields, their unique enzymatic systems and structural properties enable them to restore ecosystems while providing high-value medicinal and nutritional products. While technical hurdles regarding field acclimatization and safety must be overcome, the integration of fungi into environmental management strategies offers a promising pathway toward a cleaner and healthier world.

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Toward Smarter Food Systems: The Emerging Role of Large Language Models in Food Science

Article ID: 73581

Hanuman Anshiram Jadhav[1], Chandrasekar Veerapandian[2], V. Eyarkai Nambi[3]
[1]PhD Scholar, [2]Professor, [3]Professor,
Department of Food Plant Operations, Incubation and Entrepreneurship, National Institute of Food Technology, Entrepreneurship and Management, Thanjavur (NIFTEM-T)-613 005, Tamil Nadu, India.

Introduction

With their powerful potential to analyze data, assist decision-making processes, and extract information from various fields, including food formulation, nutrition, food safety, and logistics, large language models (LLMs), including the Generative Pre-trained Transformer (GPT) family, have become game-changing technologies in food science and technology (Kasneci et al., 2023). LLMs assist in making decisions in the food industry based on evidence and innovations through intelligent analysis of structured and unstructured data. For them to be utilized effectively, scientists, business persons, and policy makers need to collaborate and resolve issues such as data biases, ethical issues, and the need for high-quality domain data (Ma et al., 2024).

Recipe Innovation & Flavor Development

The development of new recipes and flavors has been revolutionized by using huge amounts of cooking data to develop comprehensive recipes with titles, ingredients, and cooking instructions derived from basic data such as keywords or ingredient lists, thanks to large language models that use transformers (Katserelis & Skianis, 2022). LLMs can detect the relationships between ingredients, propose new flavor pairings, and help adapt recipes across cultures using multimodal learning methods that combine textual and visual information. Thus, recipe creation becomes a more creative and data-based process compared to conventional approaches(Chhikara et al., 2024).

Food Safety & Quality Control

By enabling faster, smarter, and more automated monitoring across the entire food chain, LLMs are transforming the food safety and quality assurance sector. LLMs can detect potential contamination threats, ensure compliance with labeling standards, and forecast quality problems before they escalate by processing massive amounts of unstructured information, including supplier documents, regulation requirements, audit records, and scientific papers. By instantaneously accessing relevant safety guidelines such as HACCP, FDA regulations, or ISO 22000 standards and correlating them with actual environments, they enable intelligent chatbot systems and decision-making tools that assist food inspectors, quality control managers, and auditors. LLMs can examine manufacturing site sensor data logs and maintenance records to detect patterns connected with food spoilage or cross-contamination events. Moreover, LLMs offer multi-lingual traceability documentation, thereby making it easier for international supplier networks to maintain accurate safety records. In addition, LLMs have been deployed for reporting corrective actions, automating the detection of food allergens in ingredient lists, and conducting root cause analyses during food safety incidents (Xiong et al., 2025).

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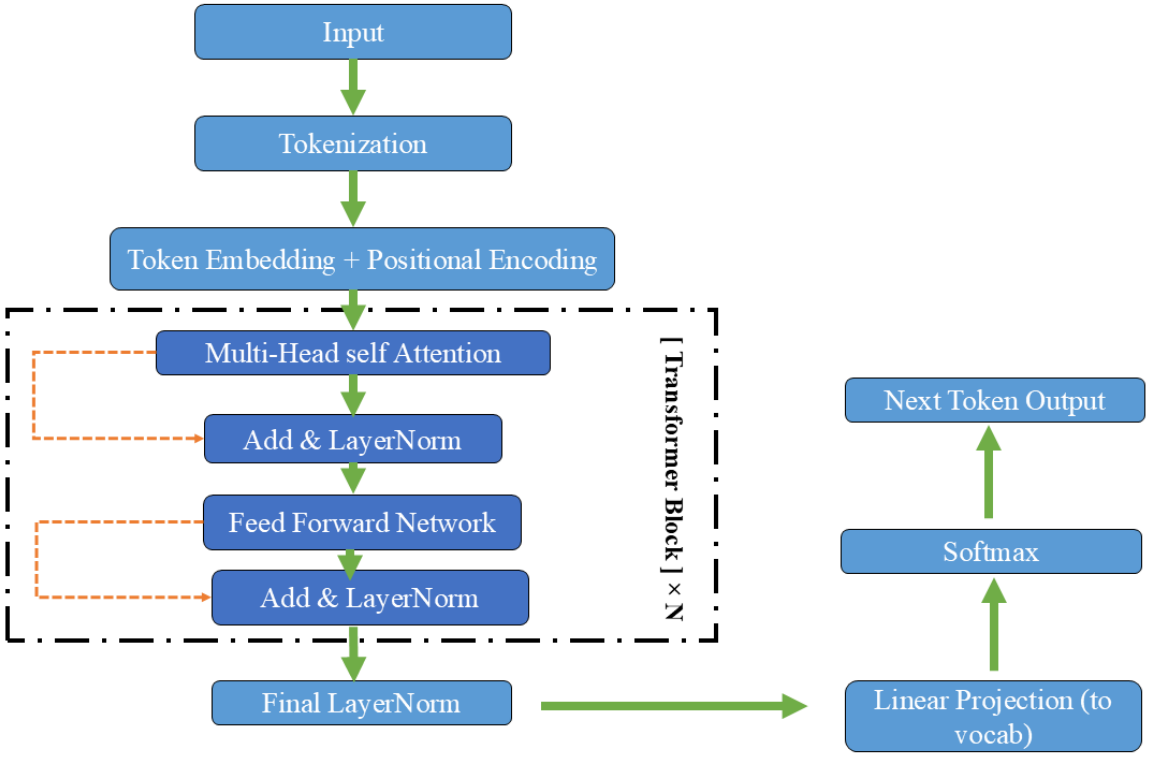


Figure 1 General architecture of a large language model (LLM)

Nutrition Science & Personalized Diets

Models such as Mistral 7B, which reach an astounding 91% accuracy rate when decoding free-text dietary restrictions, are redefining personalized nutrition in terms of being able to use natural language to communicate dietary likes and dislikes, allergies, and cultural traditions. Large language models are able to democratize personalized nutrition in the sense that they can turn a clinical service into a public one by bridging nutritional science with laymen (Aydın et al., 2025).

Supply Chain & Sustainability

Through enhanced decision-making, automation, and sustainability in crucial processes such as demand forecasting, supplier identification, contractual analysis, and sustainable procurement, LLMs are rapidly transforming supply chain management. LLMs help organizations detect disruptions early on, optimize logistics operations, and improve efficiency through unstructured data processing and contextually informed reasoning. With the human-centricity, resilience, and sustainability principles of Industry 5.0 in mind, LLMs offer vast possibilities for building socially responsible and sustainable supply chains (Song et al., 2026).

Consumer Engagement & Food Communication

By using unstructured data such as customer reviews, large language models have brought about an innovative revolution that involves consumers within the food industry. Companies are able to comprehend the complicated attitudes of their customers by refining algorithms such as InstructGPT using human inputs, which allows for greater product customization. This allows food organizations to comprehend consumer preferences, customize their products, and respond to changes in the market environment (Ma et al., 2024).

Conclusion

By enabling the latest developments in recipe creation, food safety, nutrition, logistics, and consumer engagement, Large Language Models are revolutionizing the field of food science. The use of frontier models combined with domain-specific models not only increases the breadth but also the accuracy of LLMs, while their ability to process big data enables evidence-based decisions, personalization in nutrition, and sustainability in logistics. Nevertheless, in order to harness their full potential, questions such as data bias, ethics, and access to quality domain-specific data should be considered.

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Between Home and Harvest: The Struggle of Role Conflict

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Dr. G. Swarupa Rani[1], Dr. Jessie Suneetha W[2], Dr. R. Neela Rani[3], Dr. Swetha Kodali[4], Dr. Laksmi Challa[5]
[1]AICRP on Women in Agriculture, PJT Agricultural University, Rajendranagar, Hyderabad.

Abstract

Farm women play a central role in Indian agriculture, yet their mental wellbeing is shaped by the simultaneous demands of farm work and household responsibilities. Recent estimates show that over 76% of rural women are engaged in agriculture, contributing significantly to the workforce and food production (PLFS, 2024; FAO, 2011). Despite this, women continue to face structural disadvantages, including limited land ownership (12-14%), restricted access to resources, and inadequate institutional support (Agricultural Census, 2015-16; AIF, 2024).

These constraints, combined with financial stress and weak support systems, intensify their vulnerability. A key underlying issue is role conflict, which emerges from managing overlapping productive and domestic responsibilities. This article examines how such pressures influence the mental health and wellbeing of farm women and emphasizes the need for integrated, gender-responsive interventions to enhance their quality of life and ensure sustainable agricultural development.

Introduction

The structure of Indian agriculture has undergone significant transformation in recent years, with a noticeable increase in women's participation. This shift, often described as the feminization of agriculture, is largely driven by male migration, economic pressures, and limited non-farm employment opportunities in rural areas (PLFS, 2024). As a result, women are not only supporting but, in many cases, sustaining agricultural production systems.

Their involvement spans a wide range of activities from crop cultivation and livestock care to post-harvest processing making them indispensable to rural livelihoods (FAO, 2011). However, this growing responsibility has not been matched by equal access to resources or recognition. Structural constraints such as limited land ownership, reduced access to credit and extension services, and restricted decision-making power continue to shape their experiences (Agarwal, 2018).

Beyond economic roles, women remain primarily responsible for domestic and caregiving duties, leading to an overlap of responsibilities that is both demanding and continuous. This situation creates a condition of role strain, where competing expectations from farm and household domains place pressure on time, energy, and emotional capacity (Kaur & Kaur, 2019).

Over time, such persistent strain can influence not only physical health but also mental wellbeing, coping ability, and overall life satisfaction. Examining these dynamics is essential to understanding the broader challenges faced by farm women and to designing interventions that address both their productive roles and personal wellbeing.

The Dual Burden: Home and Field

Women in rural India often spend long hours balancing agricultural labour with domestic responsibilities. Studies suggest that up to 82% of rural women participate in unpaid agricultural and domestic work, reflecting the intensity of their workload. This continuous engagement in multiple roles leads to physical exhaustion and emotional strain, leaving little room for rest or self-care.





Role Conflict

Role conflict arises when expectations from different roles clash, leading to stress and imbalance. In agriculture, this is intensified by:

1. Time pressure between farm and home responsibilities, often requiring women to multitask continuously
2. Social expectations that prioritize family and caregiving roles over productive work

3. Lack of support in sharing household work, increasing physical and mental burden

With the increasing feminization of agriculture, women are now independently managing farms in many cases, further amplifying this conflict and responsibility.

Mental Health Implications

The mental health burden on farm women is significant and often overlooked:

1. High levels of stress, anxiety, and fatigue due to continuous workload and limited rest.
2. Reduced emotional regulation and coping ability under prolonged pressure.
3. Increased vulnerability linked to financial insecurity and uncertain agricultural income.

Research indicates that mental health in agricultural communities remains underexplored, despite its strong association with livelihood stress and gender roles (Indian Council of Agricultural Research; PLFS, 2024).

Socio-Economic and Structural Realities

Recent data highlights persistent inequalities faced by farm women:

1. Women contribute nearly 60–80% of food production in India.
2. Yet, they own only about 13–14% of agricultural land.
3. Women farmers earn significantly less than men, with visible and persistent wage gaps.

These disparities increase economic dependence, limit decision-making power, and intensify both stress and role conflict (NITI Aayog).

Prevention and Coping Strategies

1. Individual Level:

a. Stress management practices such as yoga and relaxation techniques to improve mental balance.
b. Emotional resilience training to enhance coping mechanisms.
c. Awareness on mental health to reduce stigma and encourage early action.

2. Family Level:

a. Sharing household responsibilities to reduce workload burden.
b. Reducing rigid gender-based expectations within the family.
c. Encouraging a supportive and understanding family environment.

3. Community Level:

a. Strengthening Self-Help Groups (SHGs) to build collective support.
b. Promoting social participation and community engagement.
c. Developing peer support networks for emotional and practical assistance.

Evidence shows that collective action, such as farmer groups, can improve income by 15-20%, indirectly reducing stress and improving wellbeing (National Bank for Agriculture and Rural Development). Encouraging adoption of healthy coping practices, collective support mechanisms, and labour-saving technologies to reduce stress and improve overall wellbeing.







Strengthening Support Systems

Support systems play a critical role but remain relatively weak in rural contexts:

1. Low access to mental health services, especially in remote areas
2. Limited extension focuses on psychological wellbeing alongside agriculture
3. Poor social engagement and institutional support mechanisms

Strengthening these systems can act as a protective buffer against stress and role conflict, ultimately improving overall wellbeing and productivity of farm women.

Conclusion

Farm women are central to agriculture, yet they remain burdened by invisible emotional labour and structural inequalities. While they demonstrate resilience, their wellbeing is constrained by role conflict, financial stress, and weak

support systems. The future of agriculture depends not only on productivity but also on the wellbeing of those who sustain it. Investing in education, reducing gender disparities and strengthening community support systems are essential steps toward ensuring that farm women thrive not just survive.

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Soil Temperature as a Driver of Nutrient Cycling and Microbial Ecology

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Dr. Sarika J. Donga[1], Dr. Ila L. Pithiya[1]
[1]Assistant Professor, Polytechnic in Horticulture, JAU, Junagadh -362001.

Soil temperature is one of the important environmental factors of plant growth and development The exchange of heat between the soil and its surface has pronounced effect on diurnal surface temperature variations. The nature and quantum of this exchange is primarily governed by the heat capacity per volume and thermal conductivity of the soil, both of which vary with the nature of soil surface and its moisture content.

Factors Affecting Soil Temperature

Topography: Differential heating of slope surface leads to striking differences in soil temperature. The rate of transfer of sensible heat is least over a concave surface and maximum over a convex surface, leading to higher day time and lower nighttime temperature. Minimum temperature is more influenced by topography than maximum temperature.

Organic matter content: It reduces the heat capacity and thermal conductivity of soil. Moist peat and marsh soils are much colder than mineral soils in spring and warmer in winter. Dry organic soils are warmer than mineral soils in summer and cooler in winter.

Soil texture: Sandy soils with lower heat capacity warm up more rapidly than clay soils.

Soil exposure: Exposed soil surface fluctuates more widely in temperature than air by reaching higher maximum as well as lower minimum temperature.

Soil moisture: Wetter the soil, slower are its temperature changes because the specific heat of water is about 5 times as great as mineral particles.

Tillage: Cultivated soils reduce heat flow between surface and subsurface leading to higher temperature as compared to uncultivated soil.

Soil Thermal Properties

Women in rural India often spend long hours balancing agricultural labour with domestic responsibilities. Studies suggest that up to 82% of rural women participate in unpaid agricultural and domestic work, reflecting the intensity of their workload. This continuous engagement in multiple roles leads to physical exhaustion and emotional strain, leaving little room for rest or self-care.

Role Conflict

Specific heat: It is the number of thermal units (cal) required to raise a unit mass (g) of it through one degree Celsius. The value (cal g^{1}°C) for still water is 1.0, for dry sand 0.2, for humus 0.45 and mineral soil 0.18 to 0.20.

Heat capacity: It is the amount of heat required to change the temperature of 1 cc water by 1°C. Heat capacity of water is 1.0 cal cm^3 C^{-1}. It ranges from 0.3-0.6 cal cm^3 $°C^{-1}$

Thermal conductivity: It is the rate at which a substance can conduct heat. It is the amount of heat that will flow through 1.0 cm^3 of the substance in 1.0 s when the temperature difference between the opposite faces is 1.0 °C and there is no other variation in temperature. It is a true constant for chemically pure water In case of soil, it varies from place to place and with water content at a particular place. The thermal conductivity of water is 1.4 *10 cal/ cm^{-1} s^{-1} $°C^{-1}$ while that of ait is 5.7 10 cal/ cm^{-1} s^{-1} $°C^{-1}$

Thermal diffusivity: It is the ratio of heat conductivity to specific heat by volume. It is maximum at medium moisture content leading to slower conduction of heat in both very dry and very wet soil. However, the quantum of heat flow is much greater in a wet soil. Its value at zero soil moisture content is 0.0020, at 20 per cent content 0.0072 and at 40 per cent content 0.0061 cm^2/sec. When air in the soil pores is driven out by water, a large increase is brought about in density, soil heat capacity and thermal conductivity (While the thermal conductivity and heat capacity increase with moisture-content the Thermal diffusivity first increases in respect of dry soil but begins to decrease after reaching a flat maximum.

Since in fair weather, the surface layer of soil is very much drier during the day, they reabsorb moisture during night. There is an upward movement of moisture in vapour phase and in such case a diurnal variation of thermal conductivity is expected. Thus, thermal conductivity is small and wetter soil does more slowly because of large heat capacity. A temperature gradient in unsaturated soil makes water evaporate in the warmer region, diffuse as vapour through the air space and condense on cool region.

Diurnal and Seasonal Changes

The exchange of radiation at soil surface causes daily and yearly variations of soil temperature. There are considerable fluctuations in soil temperatures and heat flux due to irregular changes in weather. Thus, the soil temperature varies in regular pattern reflecting both annual and diurnal cycles of solar radiation. Fluctuations in temperature due to duration and intensities of changes in weather conditions such as cloudiness, rain, warm and cold spells, etc are also superimposed on these regular cycles.

The temperature of surface soil varies according to incoming radiation during the day. increasing to a peak value during noon and falling thereafter. During the night also it falls but much more slowly than during the day. Soil temperature below the soil surface tend to follow the changes in surface but, the diurnal variation is reduced gradually. Diurnal amplitude also decreases considerably with depth.

Variations in soil temperature are brought about at earth surface by daily and annual variations. The oscillation period of heat cycle is 86,400 s for diurnal cycle and 365.25 times of that for annual cycle. The penetration depth, which is the depth at which the soil temperature fluctuation is reduced to 0.01 of its surface values, fluctuates in respect of wet and dry soils with specific diffusivity values. For wet sand, the daily and annual fluctuations in penetration depths are 0.76 and 14.5 m respectively as against only 0.24 and 4.6 m in the case of dry sand.

In the first metre of the soil, there are rapid changes in temperature, lapse rate, etc, according to changes in weather, similar to those within the first km of the atmosphere. Effect of largescale weather irregularities and seasonal changes would penetrate to much lower depths of soil. The daily and annual heat variations penetrate deeper in the soil with good conductivity, which gives off less heat to the adjacent air during the day. It has lower daily maximum and higher daily minimum temperature. Thus, more heat is retained in such soils.

Measurement of Soil Temperature

Soil temperature up to 50 cm depth is usually measured by mercury in glass thermometers which are of two types those with straight stem having a bend of about 120° just above the bulb those in which the stem is bent above the soil surface and capillary tube lies parallel to the ground. Access tubes which can be closed at the top can be used for recording temperatures at deeper layers.

Underground sensors like bimetallic coils, thermistors, thermocouples, resistant thermometers which can be connected to a distant recorder can be used instead of fixed above ground installations to avoid problems in periodic intercultural operations. Variations in sod temperature with depth and time can be represented in three different graphs

Drawing of isotherms with time as abscissa and depth" ordinate. Such isotherms in ground are known as geotherms.

Drawing of tautochrones for showing variation in soil temperature with definite period of time by taking temperature T as abscissa and depth for a as ordinate

Drawing soil temperature pattern for selected depths of soil by taking time and temperature 7 as ordinate as abscissa

Soil Temperature and Crops

Soil aeration: Increase in soil temperature tends to decrease mass flow but increases diffusion which is important in exchange of gas between soil and atmosphere

Water retention: Increase in soil temperature increases moisture retentive capacity of soil due to expansion of soil air packets. Such increase is more in fine textured than coarse soil, but the relationship is not linear.

Movement of water vapour: Temperature gradients in soil leading to vapour density gradients are necessary for vapour phase movement of water in soil. At any given soil temperature gradient, maximum movement occurs at an optimum soil moisture content.

Soil temperature and microbial activity: The microbial activity is severely curtailed outside the range of 10°-40°C. In tropics, build-up of soil fertility through organic manures is limited by high soil temperature. Optimum temperature range for nitrite and nitrate formation is 25-30°C and that to ammonification 15°-40°C.

Soil Temperature and Plant Processes

Water absorption: Water absorption by plants is slow both at low and high temperatures. Slower elongation of roots, increase in viscosity of water, increased protoplasm viscosity and decrease in permeability of roots leading to slower movement of water through roots may operate under conditions of low soil moisture. At higher soil temperature, decrease in water absorption is due to faster maturation and root injury.

Nutrient uptake: Nutrient absorption increases with temperature up to certain level, especially in the case of anionic forms. Conversion of nitrates to organic nitrogen and their translocation retards at low soil temperatures.

Nodule formation: Optimum soil temperature for nodule growth is around 24°C. As such, nodule size decreases during summer season when the crop is subjected to soil moisture stress. Germination: Soil temperature influences the seed germination. Minimum and optimum temperatures for different crops are given in Table 1.

TABLE -1. Minimum and optimum temperatures for seed germination:

Sr. No.	Crop	Minimum (°C)	Optimum (°C)
1	Wheat, barley and oat	4-5	20
2	Rice	10-15	31
3	Maize	8-10	20
4	Sorghum	12-13	25
5	Soybean	8-9	29
6	Tobacco	13-14	29
7	Cotton	14-15	33
8	Citrus	15	30
9	Tomato	11-18	18-25
10	Cucumber	11-18	25-30
11	Forage crops	15	25-30

There are several cases where soil temperature is more important than air temperature to plant growth. High soil temperature in tropics causes degeneration of tubers in potato. There may not be any tuber formation above a soil temperature of 29°C. Corn yield increases with increase in soil temperature from 15 to 27°C Beyond this temperature the yield gradually decreases. Soil temperature, thus, has profound influence on growth, development and yield of several crops.

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Value Addition of Rose Flower

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Dr. Satish Kumar[1], Rajesh Kumar[2], Miss Kumari Rekha[3]
[1]Assoc. Prof.-cum Sr. Scientist, Dept. of Hort. (Vegetable Science), MBAC, Agwanpur, Saharsa.
[2]Assoc. Prof.-cum Sr. Scientist, Dept. Soil Science, MBAC, Agwanpur, Saharsa.
[3]Asstt. Prof. - cum- Jr. Scientist, Dept. of Genetics and Plant Breeding MBAC, Agwanpur, Saharsa.

Introduction

Rose, is a designated as the Queen of flowers, is mostly renowned for its fragrance and beauty.It is considered s a symbol of love, beauty and fragrance. There are more than 300 species of rose and thousands of cultivars. These are mostly cultivated in countries like India, Bulgaria, Iran etc. Floriculture industry is one of the most profitable agro-industries in India. There are multiple uses of flowers in everyday life due to its aesthetic value, varying colors, fragrance, texture, and diverse form ((Kumari et al, 2018).Value addition is a method used to increase the economic value, improve employment and reduce post-harvest losses while also improving the living standards of poor farmers. Value addition includes the processing, packaging and application of multiple other methods. Flowers are abundant in bioactive substances, vitamins and antioxidants, making them valuable for the nutraceutical sector, which is increasingly recognizing their health benefits (Nagajyothi and Pratheeksha, 2023). Flowers are widely used in the cosmetic industry owing to the natural antioxidants present in them and its revitalizing and calming effects on the skin. Cosmetic products like lotion, soap, toner, perfumes, shampoo, mask, face and hand cream, face and body wash has different flower extracts in them which adds value to flowers. Innovative techniques, such as nanofiltration of antioxidant-rich residual water from hydrodistillation of Rosa damascena petals, have also been demonstrated as effective for recovering valuable bioactive compounds (Stoyanova et al., 2025). Value addition in rose (*Rosa spp.*) significantly enhances the economic, nutritional and industrial potential of this versatile crop. Rose petals and hips, rich in antioxidants, polyphenols, anthocyanins, vitamins and essential oils, can be transformed into a wide array of products such as gulkand, rose syrup, jams, teas, rose water, essential oils, rose hip juice and oil, floral beverages, sweets, powders, potpourri and infused oils like Gul Roghan. These products not only preserve the delicate aroma, flavor and bioactive compounds of roses but also offer health benefits such as antioxidant, anti-inflammatory, digestive and skin-nourishing effects. The growing consumer preference for natural, herbal, and functional foods has further increased the demand and market potential for rose-based products, providing opportunities for small and large-scale agro-industries, rural entrepreneurship, export markets and sustainable livelihoods.

Requirement of Value Addition

1. Eco-friendly manners to add value to perishable produces.
2. Increased availability throughout the year.
3. Increased scope of employment.
4. Generation of new and novel products for the market.
5. Reduction in post-harvest losses of 45%.

Nutritional Composition of Rose Petals and Hip

Rose petals are nutritionally significant in addition to being aromatic. Carbohydrates are the predominant component, including natural sugars such as glucose, fructose and sucrose. They contain small amounts of proteins and minerals along with organic acids like malic acid and quinic acid that impart mild tanginess. Rose petals are rich in polyphenols and anthocyanins, particularly cyanidin-3-glucoside, which exhibit strong antioxidant and radical-scavenging properties. These compounds help reduce oxidative stress, support cardiovascular health, and contribute to anti-inflammatory and anti-aging effects. Ffruit of flower called hip which are rich in vitamin C.

Value Added Products of Rose

Rose water: To make rose petals, 100kg of rose petals are boiled in 1000L of water and then distilled. It is used in food industries and also important for many religious ceremonies. It can also be applied directly on face as a moisturizer.
Rose perfume: Rose oil is a product that is produced by steam distillation of rose petals.

Rose oil Rose Otto and Absolute)/ Gul Roghan: Among all the species of rose, Rosa damascena Mill contains the highest amount of oils ranging between 0.032-0.049%. to extract 1kg of rose oil, nearly 3000-4000 kg rose petals are required. . The main compounds found in essential oil in rose are: ß-citronellol, transgeraniol, n-heneicosane, n-nonadecane, nonadecene, phenylethyl alcohol, linalool. Rose oil contains multiple medicinal properties due to which it is also used in ayurveda as well as pharmaceutical companies. Rose extract is also used in mouthwash, treatment of ulcers and painkiller effects. It also contains anti-inflammatory effects. Rose oil also contains anti-cancer, antidepressant, anti-

microbial and anti-bacterial properties. It also contains memory enhancement properties and hence is recommended for Alzheimer's disease.

Gulkand: After slight shade drying to remove surface moisture, the petals are finely chopped or gently crushed and mixed thoroughly with an equal or slightly higher quantity of sugar, generally in a 1:1 or 1:1.5 ratio. After proper maturation, the gulkand develops a rich aroma, glossy appearance and smooth semi-solid consistency and it is stored in airtight containers in a cool place, where it serves as a cooling, digestive and mildly laxative preparation in traditional food and medicinal systems.

Rose concrete: Rose concrete, also called as rose absolute, is highly concentrated aromatic substance that is extracted from the petals by the process of solvent extraction. It is produced by processing of roses with different solvents to produce a semi-solid, waxy substance that contains the volatile aromatic compounds responsible for its unique fragrance. It is mostly known for its rich and deep fragrance. Due to its high concentration of these aromatic compounds, it is a highly valuable ingredient by perfume industries.

Rose Syrup

Rose syrup is a concentrated sweet beverage base prepared by extracting the natural color, flavor and aroma from fresh fragrant rose petals, commonly obtained from Rosa damascena, Fresh petals are carefully cleaned, slightly crushed to rupture the tissues and mixed with sugar in approximately a 30:70 (petal:sugar) ratio to facilitate osmotic extraction of pigments and volatile compounds. This mixture is kept undisturbed for about 24–48 hours. The finished syrup is cooled to room temperature, filled into sterilized glass bottles, sealed tightly and stored in a cool, dry place, where it serves as a refreshing base for beverages, desserts and traditional drinks when diluted with water or milk.

Rose Petal Jam: Rose petal jam is a sweet, aromatic preserve made from edible rose petals and sugar. Rose petal jam is enjoyed as a spread on bread, in desserts, or as a flavorful ingredient in various confectionery preparations, offering a natural floral aroma and subtle sweetness.

Potpourri

Potpourri is a decorative and fragrant product prepared by combining dried rose petals with aromatic spices such as cinnamon, dried lavender, and other natural ingredients. The dried petals are blended with a few drops of rose essential oil to enhance fragrance and then stored in a sealed container for several days to allow the scents to meld. Once matured, the mixture is placed in decorative bowls, sachets, or gift items, providing a long-lasting natural aroma for homes, offices, and special occasions.

Dried flower: Roses for dry flower are preferred at bud-stages.

Challenges and Problems

Commercialization of rose-based products faces several constraints. High-quality production requires careful species selection, precise harvesting, and hygienic handling, which are labor-intensive. The perishable and seasonal nature of petals and hips, along with susceptibility to microbial spoilage, limits consistent supply. Processing for essential oils and other products demands large quantities and skilled labor, increasing costs. Variability in species, climate, and techniques affects quality, while small-scale growers often lack knowledge of modern processing and storage. Competition from imports and low market awareness further challenge profitability, highlighting the need for training, innovation, and standardized sustainable practices.

Conclusion

Value addition is an important sector for proper utilization of fresh rose flower. Diversification of rose-derived products increases profitability, reduces post-harvest losses, and promotes sustainable agro-based entrepreneurship, while growing consumer demand for natural and functional products underscores the global economic importance of Rosa spp.

Roses (Rosa spp.) are a multipurpose crop with opportunities for value addition in food, cosmetic, medicinal, and decorative sectors. The aromatic compounds, essential oils, polyphenols, anthocyanins, vitamins, and unsaturated fatty acids in petals and hips enable the production of nutritionally rich and therapeutically beneficial products. With careful species selection, timely harvesting, and hygienic processing, high-quality products such as gulkand, syrups, jams, rose water, essential oils, rose hip beverages, sweets, powders, and infused oils can be produced.

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The Digitization of Agricultural Industry: Futurist

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Dr. Satish Kumar[1], Mrs. Kumari Rekha[2], Dr. Mrinalini Kumari[3]
[1]Assoc. Prof.-cum Sr. Scientist, Dept. of Hort. (Vegetable Science), MBAC, Agwanpur, Saharsa.
[2]Asstt.Prof. -cum- Jr. Scientist, Dept. of Genetics and Plant Breeding, MBAC, Agwanpur, Saharsa.
[3]Asstt. Prof. cum- Jr Scientist, Dept. of Entomology, MBAC, Agwanpur, Saharsa.

Introduction

India's prosperity depends upon the Agricultural prosperity. There are many kinds of agricultural products produced in India and the marketing of all these farm products generally tends to be a complex process. Agricultural marketing involves many operations and processes through which the food and raw materials move from the cultivated farm to the final consumers. The conventional approach of extension services have not been able to resolve the challenges posed by various factors in Indian Agriculture marketing. It is found that the Agriculture growth of competitiveness and efficiency of enterprises in any areas of activity is possible only through the implementation of innovative transformations (Kolmykova, et al.2017). The experience of innovative companies shows (Buraeva,2020) that the use of digital technologies can improve the efficiency of economic activities, reduce operating costs, as well as the costs of storing and transporting products.The Internet of Things, cloud computing, big data, block chain, artificial intelligence have ample opportunities for application in the agricultural sector (Bilali and Allahyari, 2018). The Indian Govt. is being made a remarkable achievements especially in the area of agriculture by giving various facilities to the farmers in which the ICT services is one among which is helping the farmers to understand the modern cultivation methods, availability of agriculture inputs, irrigational sources, availability of pesticide and fertilizers for increasing the production and productivity of crops (Patel and Sayyed (2014). The development of digital economies in both developed and developing countries will help stabilize the national economy based on their development priorities. It is about using all possible digital media, tools, technologies and methods to market valuable offerings to the customers by conversing internet, digital technology options, distributed customer intelligence, creativity, talent and needs with the companies' capabilities and resources so that long term sustainable competencies can be generated. A part of problem is also related to irregular use of pesticides and herbicides and misuse of available technology which cause harm to crop and eventually resulting in agricultural wastes (Abbasi, et 2021)These issues can be addressed by integrating sophisticated technologies and computer based applications that ensure high crop yield, less water consumption optimised pesticide/herbicide utilization, and enhanced crop quality. This agriculture farmimg called smart Agriculture cultivation which linked with disruptive digital technologies such as Internet of Things (IoT), big data and analytics (BDA), system integration (SI), cloud computing (CC), simulation, autonomous robotic systems (ARS), augmented reality (AR), artificial intelligence (AI), wireless sensor networks (WSN), cyber-physical system (CPS), digital twin (DT), and additive manufacturing (AM) to enable the digitization of the industry (Aceto, et al 2019).

Agriculture Enabling Technologies

Internet of Things driven agricultural systems: Internet of things (IoT) refers to a cosmos of interrelated computing devices, sensors, appliances, and machines connected with the internet, each having unique identities and capabilities for performing remote sensing and monitoring (Pylianidis, S Osinga, 2021). In the agricultural domain, IoT devices in the physical layer gather data related to environmental and crop parameters such as temperature, humidity, pH value, water level, leaf color, fresh leaf weight, etc. The transmission of this data takes place in the network layer, the design of which depends on the selection of suitable communication technologies relevant to the field size, farm location, and type of farming method. For instance, ZigBee, LoRa, and Sigfox are widely used and employed in outdoor fields because they are cheaper and have low energy consumption and a good transmission range [Shaikh et al2010]. Despite being a secure technology, Bluetooth is only used in indoor farms as it offersa short transmission range (Shaikh et al 2010). Wi-Fi is not a promising technology for agricultural applications due to its high costs and high energy consumption Shaikh 2010 RFID (radio frequency identification) and NFC (near field communication) technologies, on the other hand, are increasingly being implemented in agricultural systems for tracking agricultural products (Kour, & Arora 2020).

Wireless sensor networks in agriculture: Wireless sensor network (WSN) is regarded as a technology that is used within an IoT system. It can be defined as a group of spatially distributed sensors for monitoring the physical conditions of the environment, temporarily storing the collected data, and transmitting the gathered information at a central location ***(Shaikh et al 2010)***

Cloud computing in agriculture: It provide inexpensive storage services for data gathered from different domains through WSNs and other preconfigured IoT devices. The cloud-based agricultural systems have the potential to solve problems of increasing food demands, environmental pollution caused by excessive use of pesticides and fertilizers, and the safety of agricultural products.

Autonomous robot systems in agriculture: Autonomous robot systems (ARS) are intelligent machines capable of performing tasks, making decisions, and acting in real-time, with a high degree of autonomy (without external influence or without explicit human intervention) (R Rahmadian, and Widyartono 2020). The agricultural robots use a combination of emerging technologies such as computer vision, WSNs, satellite navigation systems (GPS), AI, CC, and IoT, thereby facilitating the farmers to enhance productivity and quality of agricultural products. AARS in smart farming can be mobile AARS, which can move throughout the working field, or fixed AARS (Bechar & Vigneault, 2016)

Machine learning in agriculture: ML techniques and algorithms are implemented in the agriculture sector for crop yield prediction, disease, and weed detection, weather prediction (rainfall), soil properties estimation (type, moisture content, pH, temperature, etc.), water management, determination of the optimal amount of fertilizer, and livestock production and management (Liakos et al. 2018).

Advantages of Digital Technology

1. Agricultural production; - increasing the efficiency of the resources used, adapting biological objects to the territorial specifics of farming;

2. Individual approach to keeping and feeding livestock and poultry;

3. An increase in the quantity and quality of the crop, a decrease in the yield deviation;

4. The ability to manage the quality of manufactured products through the introduction of modern breeding and genetic developments;

5. Reducing dependence on the influence of the human factor;

6. Reduction of harmful effects on the environment; - updating the technical base of agricultural production.

7. Digital marketing can be the best possible solution

8. In addition, the cloud storage provider is responsible for backing up and maintaining data integrity and does not involve the client in this process. From an economic point of view, the introduction of digital technologies and automated control systems into the active ties of agricultural organizations makes it possible to integrate production processes into a single information space and significantly increase the efficiency of economic activities. The increase in efficiency is expressed in optimizing the operating modes of machines and equipment, increasing productivity and labor safety, improving the quality of products, their quantity, in optimizing logistics, and reducing the time to market products.

Conclusion

Indian context is full of technology gaps between marketer and customers. In some places, customers are not ready for the advance technology-based business transformation, so marketer must move quite slowly. Reasons for these gaps may attribute to educational or literacy gap, poor infrastructural expansion, uneven regional economic development, linguistic variability, unevenly scattered population (problem of reach), exposure gaps etc. These gaps can be tackled by creating proper infrastructure and awareness about the digital platforms and conducting trainings, demonstrations on how to use them efficiently.

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Export Potential of Mango in India

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Dr. Satish Kumar[1], Dr. Mrinalini Kumari[2], Mrs. Kumari Rekha[3]
[1]Assoc. Prof.-cum Sr. Scientist, Dept. of Hort.(Vegetable Science), MBAC, Agwanpur, Saharsa
[2]Asstt. Prof. - cum- Jr. Scientist, Dept of Entomology, MBAC, Agwanpur, Saharsa
[3]Asstt. Prof. - cum- Jr. Scientist Dept. of Genetics and Plant Breeding, MBAC, Agwanpur, Saharsa

Introduction

Mango, "The King of Fruits" is known for its taste, flavor, attractive color and nutritional value. India is the world's largest producer of mangoes, contributing approximately 41% of the global production (FAO, 2021). The important mango producing states in India are Andhra Pradesh, Utter Pradesh, Karnataka, Bihar, Gujarat, Maharashtra, Tamil Nadu, West Bengal, Kerala and Odissa. Major producing states, such as Uttar Pradesh, Bihar Andhra Pradesh, and Maharashtra, contribute over 75% of the national output (DES, 2021). Government initiatives, such as Operation Greens, MIDH, and the Agricultural Export Policy (2018), aim to improve infrastructure and export competitiveness (MoA & FW, 2020). Despite this, its share in global mango exports is only approximately 5-6% (APEDA, 2021), mainly due to poor post-harvest management, limited cold chain infrastructure, and lack of value addition (Reddy & Reddy, 2020). India's rich varietal diversity Alphonso, Kesar, Jardalu, Dashehari, etc. offers scope for branding and premium positioning in global markets. In 2022-23, India exported 289.78 thousand metric tonnes of mango and mango products, earning Rs. 3,519.20 crore. From India major mango importing countries are United Arab Emirates, Bangladesh, United Kingdom, Saudi Arabia, Kuwait, Qatar, Bahrain, Nepal, United States of America, Oman, Singapore etc and the foreign exchange earned from such exports amounts to about Rs. 2005 millions (Biswas and Lalitkumar, 2011). India's agri-exports touched $50 billion in 2023-24, with mango as a priority (MoC&I, 2025).APEDA should play a vital, active and dynamic role in export of mango and mango products. India launch Mango Festival at national and International level to boosts export potential of mangoes and its product, with the help of the Agricultural and Processed Food Products Export Development Authority (APEDA). Several factors increase the growing global demand the rising health consciousness, the popularity of exotic fruits and the growing Indian diaspora that sparks interest in the traditional Indian taste. Other active markets that are expected to buy the premium Indian varieties as preferred by consumers include the UAE, USA, UK, and Saudi Arabia, among other markets, in 2025.

Mango Export Promotion through AEZs and Institutional Support in India

The Agri Export Zones (AEZs) initiative, launched in 2001 under the EXIM Policy, aimed to boost agri-exports through product-specific clusters. For mango, AEZs were set up in regions such as Malihabad (UP), Ratnagiri (MH), Krishna (AP), and Salem (TN), integrating farmers, exporters, and processors **(APEDA, 2005).**

Export Varieties of Mango: Alphonso, Kesar, Maldah, Gulab Khus, Jardalu, Dasheri, Langra

Table 1: Mango export zones of India:

State	Crop/ variety	District/Areas (AEZs)
Maharashtra	Mangoes (Alphonso)	Latur, Ratnagiri, Sindhudurg,
	Kesar Mango	Aurangabad, Beed, Jalna, Ahmednagar,
Uttar Pradesh	Mangoes	Lucknow, Sitapur,
West Bengal	Mangoes	Maldah
Andhra Pradesh	Mangoes	Rangareddy
Tamil Nadu	Mangoes	Madurai, Theni,
Gujarat	Mangoes	Ahmedabad, Anand, Vadodara, Surat, Navsari, Valsad, Bharuch, Narmad

Source: MoCI, 2019

Table 2: Export destinations of mango products export from India:

Product	Importing Countries
Flesh	U.A.E., U.K., U.S.A., Kuwait, Qatar, Canada, Oman, Nepal, Singapore, Bahrain
Pulp	Saudi Arabia, U.S.A., U.K., Germany, Canada, Yemen, Netherlands, Oman, U.A.E., Kuw
Jame and Jelly	Netherlands, Saudi Arabia, Russia, U.A.E., U.S.A., France, U.K., Japan, China, Kuwait
Slice in Brine	U.S.A., Netherlands, U.K., Germany, Malaysia, Israel, Bhutan, Nepal, Australia, Japan
Squash	Saudi Arabia, U.A.E., Nepal, Netherlands, Bangladesh, Libya, Liberia, China, Spain
Juice	Netherlands, U.S.A., Korea, Australia, Bhutan, Qatar, Canada, Austria, Malaysia
Sliced Dried	U.A.E., Qatar, Nepal, Turkey, Mexico, Kuwait, U.S.A., Singapore, U.K., Saudi Arabia

Table 3: Export specifications for mango varieties:

Parameter	Variety	Middle East	Netherlands / Germany	UK	Japan	USA
Weight	Alphonso	200-250 g	250-300 g	250-300 g	250-300 g	250-300
	Kesar	200-250 g	225-250 g	225-250 g	250-300 g	250-300
Packing		1	1	1	1	1
Storage Temperature		13°C	13°C	13°C	13°C	13°C
Transportation		By Sea	By Air	By Air	By Air	By Air

(Source: APEDA, 2021)

Top Destinations for Indian Mango Exports	Top Mango Exporters in India
United Arab Emirates (UAE) United States of America (USA) United Kingdom (UK) Japan South Korea New Zealand Australia Saudi Arabia Qatar Oman Kuwait	•Reliance Industries Limited •Organic India Private Limited •Shreevali Agro •INI Farms •Nik May Exports LLP •VNS Food LLP •Ryushi Naik •AGS Mega Mart •Sai Shagun Food Industries •Jai Kishan Products •Jceify Exporters Pvt. Ltd.

Top HS Codes for Mango Export from India

HS Code	Product Category
08045010	Fresh Alphonso mangoes
08045020	Fresh Kesar mangoes
08045030	Fresh Totapuri mangoes
08045040	Other fresh mango varieties
20079910	Mango pulp, prepared or preserved

Constraints in Mango Export

1. Fluctuations in output due to weather conditions – Unpredictable weather, including. Droughts, excessive rainfall, and temperature variations affect mango yield and quality.

2. Costly transportation – High logistics costs, including cold chain requirements, make mango exports are expensive.

3. Lack of gradation and quality control – Inconsistent grading and quality standards reducing competitiveness in international markets.

4. Excessive use of pesticides and insecticides – Residue levels exceeding permissible limits can lead to rejection by importing countries.

5. Marketing problems – Limited market access, inadequate branding, and lack of Promotional efforts hinder exports.

6. Inefficient post-harvest management – Poor handling, storage, and processing lead to spoilage, and reduced shelf life.

7. Suitability of few varieties for exports – Only select mango varieties meet international preferences, and phytosanitary requirements.

8. High freight charges: Expensive air and sea freight increase export costs.

9. Limited cargo space – Availability of refrigerated cargo space is often insufficient for large shipments.

10. High packaging cost and poor labelling – Expensive packaging and non-compliance with labelling regulations affect market acceptance.

Conclusion

There are immense scope in mango export to get foreign exchange money, upliftment of socio-economic condition and employment generation.For Scaling of export of mango, improvements are needed in cold chain systems, post-harvest practices, varietal research, and compliance with global standards. Government schemes such as AEZs, ODOP, and MIDH offer policy support, but greater investment in infrastructure, certification, and branding is vital step. Strengthening these areas can enhance exports, reduce waste, and increase rural income, thereby realization of positive manifestation in the global mango market.

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Export Potential of Vegetables

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Dr. Satish Kumar[1], Mrs. Kumari Rekha[2], Rajesh Kumar[3]
[1]Assoc. Prof.-cum Sr. Scientist, Dept. of Hort. (Vegetable Science), MBAC, Agwanpur, Saharsa.
[2]Asstt. Prof. - cum- Jr. Scientist, Dept. of Genetics and Plant Breeding, MBAC, Agwanpur, Saharsa.
[3]Assoc. Prof.-cum Sr. Scientist, Dept. of Soil Science, MBAC, Agwanpur, Saharsa.

Introduction

Vegetables play important role in food and nutritional security. India ranks second in the production of vegetables. Generally, vegetables are widely designated as "protective foods" in human diet due to their varied health benefits attributable to the richness in vitamins, essential fatty acids, minerals, amino acids and dietary fiber and various essential bioactive compounds (Da Silva et al. 2017). The World Health Organization recommends consuming at least 400 g of fruits and vegetables daily to reduce the risk of cardiovascular diseases and certain cancers (Wu, et al. 2022). As per National Horticultural Database during 2024-25, India produced 219 million tonnes vegetables. The area under vegetable cultivation is 10.25 to 11 million hectares. India exports their produce mainly to Bangladesh, Nepal, United Arab Emirates, United Kingdom, Malaysia, Saudi Arabia, Bahrain and Kuwait. Policies of foreign trade play an important role in the country's economic development, income, employment, and exchange earnings and increase bilateral and multilateral relations at the international level. With growing global concerns regarding food safety, environmental protection, and sustainable development, the application of smart packaging technology in modern fruit and vegetable preservation has become a key driver of innovation in both agriculture and the food industry (Kang, et al. 2023) toward exporting of vegetable produce.

Quality Fresh Vegetables

1. Vegetable products grown using the least of insecticides and herbicides,
2. Vegetable products only marketed to exclusive markets for consumers with high purchasing power,
3. Vegetable products are generally consumed in the luxury hotels, in international aircraft flight catering and other western dishes.

Strategies to Overcome Challenges

Government Support and Policy Interventions: The Indian government plays a crucial role in facilitating vegetable exports through supportive policies and initiatives. By providing subsidies, , Agricultural Export Zones (AEZs) .

Strengthening Agricultural Infrastructure: Improving agricultural infrastructure is essential for supporting the growth of vegetable exports. This cold storage facilities, better transportation networks, and modern processing and packaging units.

Capacity Building and Farmer Education: Educating farmers about the requirements of export markets and providing them with the skills needed to meet these demands is critical. Training programs on good agricultural practices (GAP), organic farming, and post-harvest handling can help farmers produce export-quality vegetables. Extension services and farmer cooperatives can also play a vital role in disseminating knowledge and facilitating access to export opportunities.

Access to Finance and Risk Mitigation: Improving access to finance is essential for enabling farmers to invest in export-oriented production. Microfinance institutions, cooperative banks, and government schemes can provide farmers with the capital needed to upgrade their practices and enter export markets.

Promotion of Export-Ready Varieties: Developing and promoting vegetable varieties that are particularly suited for export markets.

Some Case Studies of Successful Vegetable Exporting

The Success of Onion Exports from Maharashtra: Maharashtra is one of the leading states in India for onion production and export. The region's success in exporting onions is attributed to a combination of favourable climate, government support, and the establishment of export-oriented infrastructure. Farmers in Maharashtra have benefited from targeted government policies, such as subsidies for storage facilities and transport, as well as training programs on export standards. As a result, Maharashtra's onions are now in demand in markets across the Middle East and Southeast Asia.

The Rise of Okra Exports from Gujarat: Gujarat has emerged as a significant exporter of okra, particularly to markets in the Middle East. The state's farmers have adopted advanced farming practices, including drip irrigation and integrated pest management, to produce high-quality okra that meets international standards. Government initiatives, such as the

establishment of export zones and the provision of market information, have further supported farmers in accessing global markets

Broccoli Cultivation and Export from Himachal Pradesh: Himachal Pradesh, with its cooler climate, has become a hub for the cultivation and export of broccoli. The state's farmers have successfully transitioned from traditional crops to high-value vegetables like broccoli, which fetch premium prices in international markets. Government support in the form of training programs and subsidies for greenhouse farming has played a crucial role in this transformation. The success of broccoli exports from Himachal Pradesh serves as a model for other states looking to diversify their agricultural portfolios.

Economic Benefits for Indian Farmers

Increased Income and Profit Margins: One of the most significant economic benefits of vegetable exporting is the potential for increased income for farmers.

Diversification of Income Sources: Exporting vegetables provides farmers with an additional income stream, reducing their reliance on domestic markets, which can be volatile. This diversification of income sources helps mitigate risks associated with price fluctuations, crop failures, and other challenges in the domestic market. By exporting, farmers can achieve a more stable and predictable income.

Employment Generation and Rural Development: The growth of vegetable exports has a ripple effect on rural economies. This creates employment opportunities in rural areas, contributing to rural development and reducing migration to urban centers.

Access to Better Farming Practices and Technologies: This includes the use of high-quality seeds, precision farming techniques, and advanced post-harvest handling methods. As farmers upgrade their practices to meet export requirements, they gain access to knowledge and technologies that can improve overall farm productivity.

Challenges in Vegetable Exporting

Stringent Quality Standards and Compliance: One of the major challenges faced by Indian farmers in the export market is the stringent quality standards imposed by importing countries. These standards often include requirements related to pesticide residue levels, packaging, and certification. Meeting these standards can be difficult, particularly for smallholder farmers who may lack the resources to invest in the necessary technologies and practices.

Logistical and Infrastructure Constraints: The export of fresh vegetables requires efficient logistics and infrastructure to ensure that produce reaches international markets in good condition. India's agricultural infrastructure, particularly in rural areas, often falls short of the requirements for efficient export operations. Issues such as inadequate cold storage facilities, poor transportation networks, and delays at ports can lead to significant losses due to spoilage and reduced shelf life.

Market Access and Competition: Gaining access to international markets can be challenging, especially for small and medium-sized farmers who may lack the resources and connections to enter global supply chains. Moreover, Indian farmers face competition from other countries that produce similar vegetables, sometimes at lower costs or with better-established trade relations. Competing in these markets requires not only meeting quality standards but also offering competitive prices and ensuring timely delivery.

Financial Barriers: Exporting vegetables requires investment in quality inputs, certification, packaging, and transportation. For many farmers, particularly smallholders, these costs can be prohibitive. Access to finance remains a significant barrier, with many farmers struggling to secure loans or credit at reasonable interest rates. Without financial support, it is difficult for farmers to scale up production and participate in export markets.

a. Inability to meet quality requirements for export
b. Poor storage and transport facilities
c. Dependency on pesticide usage
d. Lack of Institutional supports

Future Prospects and Opportunities

Expanding to New Markets: As global demand for fresh vegetables continues to grow by creating new markets beyond the traditional destinations. Countries in Africa, Eastern Europe, and Latin America represent untapped markets with potential for growth. By conducting market research and developing export strategies tailored to these regions, Indian farmers can expand their reach and increase their export volumes.

Organic and Sustainable Farming as a Niche Market: The global trend towards organic and sustainably produced food offers Indian farmers a niche market opportunity. By adopting organic farming practices and obtaining certification, farmers can cater to consumers who are willing to pay a premium for organic produce. This not only adds value to the exported vegetables but also aligns with the global movement towards more sustainable and environmentally friendly agriculture.

Leveraging Technology for Better Market Access: Technology can play a pivotal role in overcoming some of the challenges associated with vegetable exporting. E-commerce platforms, mobile apps, and digital supply chain solutions can help farmers connect directly with international buyers, streamline logistics, and ensure transparency in transactions. Additionally, the use of block chain technology can enhance traceability and build trust with consumers in export markets.

Enhancing Brand Recognition for Indian Vegetables: Building a strong brand for Indian vegetables in international markets can help differentiate them from competitors. Branding initiatives that highlight the quality, taste, and sustainability of Indian produce can attract premium customers and foster long-term relationships with international buyers. Government and industry bodies can collaborate on promotional campaigns and trade shows to showcase Indian vegetables on the global stage.

Conclusion

The export of vegetables presents a significant economic opportunity for Indian farmers. By tapping into global markets, farmers can increase their incomes, diversify their livelihoods, and contribute to the growth of India's agricultural economy.

The examination of export growth in major fresh fruits and vegetables from India indicates a clear upward trajectory. These findings suggest that India possesses the potential to further amplify its global market footprint, thereby fostering economic growth. We need to focus our policies on increasing the exports of these crops. Exporters and processors must be encouraged to buy directly from Farmer Producer Organizations (FPOs) to ensure that farmers receive fair prices and to strengthen the supply chain for these crops. Attention may be given to the diversification of fruits and vegetables exports and more destinations with improved infrastructure, trained human resources, and support facilities to move up the value chain and meet international standards like sanitary and phytosanitary measures, etc. So. Export potential generates income, employment, and sustainable development.

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Crop Diversification for Sustainable and Profitable Farming

Article ID: 73588

Sagarla Sowmyasri[1], Vikram Nalabolu[1], K. Mamatha[2]
[1]Ph.D. Scholar, Department of Agronomy, PJTAU, Hyderabad, Telangana.
[2]Scientist, RARS, Palem, PJTAU, Hyderabad, Telangana.

Abstract
Crop diversification is emerging as a sustainable approach to overcome the challenges associated with monocropping systems in Indian agriculture. Continuous cultivation of a single crop has led to declining soil fertility, increased pest incidence and unstable farm income due to market fluctuations. Diversification helps in improving soil health, enhancing resilience and increasing income opportunities for farmers. This article highlights the importance of crop diversification, supported by practical examples and the role of cooperatives in strengthening market access.

Keywords: Crop diversification, Monocropping, Soil health, Farm income, Market access, Sustainable agriculture.

Introduction
Agriculture is a major source of livelihood in India, supporting a large section of the population. However, continuous monocropping practices have created several challenges such as soil degradation, declining productivity and increased vulnerability to climate and market risks. Farmers cultivating a single crop repeatedly often face problems related to nutrient imbalance, pest outbreaks and unstable income.

In recent years, crop diversification has gained importance as an effective strategy to address these challenges. Farmers are gradually shifting towards diversified cropping systems involving pulses, oilseeds, and high-value crops, which improve both sustainability and profitability. Studies indicate that crop diversification can increase farm income by 20-30% under suitable conditions (Sharma *et al.*, 2022).

Problems Associated with Monocropping
Monocropping practices have led to the depletion of soil nutrients, resulting in declining crop yields over time (Kumar *et al.*, 2020). To compensate for this loss, farmers increasingly depend on chemical fertilizers, which further degrade soil health and increase production costs. Such systems are also more vulnerable to pest and disease outbreaks, leading to higher input use and economic losses. In addition, farmers growing a single crop face greater risk due to market price fluctuations, which directly affects their income stability.

Concept of Crop Diversification
Crop diversification involves incorporating multiple crop species into a farming system through various strategies:

Intercropping – Growing two or more crops simultaneously in the same field

Crop rotation – Alternating different crops across growing seasons

Agroforestry – Integrating trees with crops or livestock

Cover cropping – Planting crops primarily to benefit soil health rather than harvest

Inclusion of leguminous crops plays an important role in improving soil fertility, as they fix atmospheric nitrogen and reduce dependence on chemical fertilizers (Singh and Ranjan, 2021). This practice also helps in maintaining ecological balance and improving long-term productivity.



Fig. 1. Crop diversification in agricultural fields

Diversification Planning Framework

Crop diversification can be effectively planned through a simple stepwise approach. Farmers should first assess field conditions such as soil, climate, water availability, and market demand. Based on this, suitable and complementary crops can be selected. Appropriate diversification methods like intercropping or crop rotation can then be adopted. Finally, the system should be implemented carefully and monitored regularly for better results.

Benefits of Crop Diversification

Environmental	Economic	Social
Improved soil health	Reduced financial risk	Enhanced food security
Reduced chemical inputs	Higher net returns	Better nutrition
Lower pest and disease incidence	Multiple income sources	Employment generation
Climate resilience	Market flexibility	Social stability
Biodiversity conservation	Reduced input costs	Preservation of traditional knowledge

Case Studies

The benefits of crop diversification are evident in different regions. In Maharashtra, farmers have shifted from cotton monocropping to diversified systems involving pulses, millets and vegetables, resulting in improved soil health and higher income (Sharma *et al.*, 2022).

Similarly, a farmer from Punjab transitioned from wheat monocropping to a diversified cropping system including mustard, maize and pulses. This change led to nearly a 30% increase in income along with improved soil fertility (Kumar, 2023).

Role of Cooperatives in Market Access

Market access plays a critical role in the success of crop diversification. Farmers often face challenges in marketing diversified produce due to lack of infrastructure and price information. Cooperatives and Farmer Producer Organizations (FPOs) help farmers overcome these challenges by providing better access to markets, storage facilities and collective bargaining power. They enable farmers to reduce input costs and improve profitability through economies of scale (Choudhury and Malhotra, 2022).

Cooperatives also facilitate access to improved technologies and innovative farming practices, thereby enhancing productivity (Das *et al.*, 2023). Through collective action, farmers can secure better prices and reduce risks associated with market fluctuations. Access to local markets, digital platforms, and direct marketing channels such as farmer markets can further improve price realization for diversified produce.

Conclusion

Crop diversification is a key strategy for achieving sustainable and profitable agriculture. It helps in improving soil health, reducing production risks and ensuring stable income for farmers. The support of cooperatives and improved market access further strengthens the benefits of diversification. With increasing awareness and adoption, crop diversification has the potential to transform agricultural systems and enhance long-term sustainability. Thus, crop diversification not only ensures sustainability but also enhances profitability and market resilience for farmers.

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'The Indigenous Reset' - Molecular Synergies of Ancestral Foods in the 2026 Metabolic Era

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Shraddha Joshi[1], Bhakti Pant[2], Anupriya Sharma[2]
[1]Ph.D. Research Scholar, Department of Food and Nutrition, College of Community Science, GBPUA&T, Pantnagar, Uttarakhand, India.
[2]B.Sc. (Hons.) Community Science Final Year, Department of Food and Nutrition, College of Community Science, GBPUA&T, Pantnagar, Uttarakhand, India.

The Renaissance of the Native Palate: The "Software Mismatch"

Imagine trying to run the latest 2026 high-speed app on a computer from the 1990s. It crashes. This is exactly what is happening to the human body today. We are biologically "programmed" to process the complex, rugged, and slow-burning foods our ancestors ate. Instead, we are feeding our systems "cellular noise "ultra-processed calories that our DNA doesn't recognize.

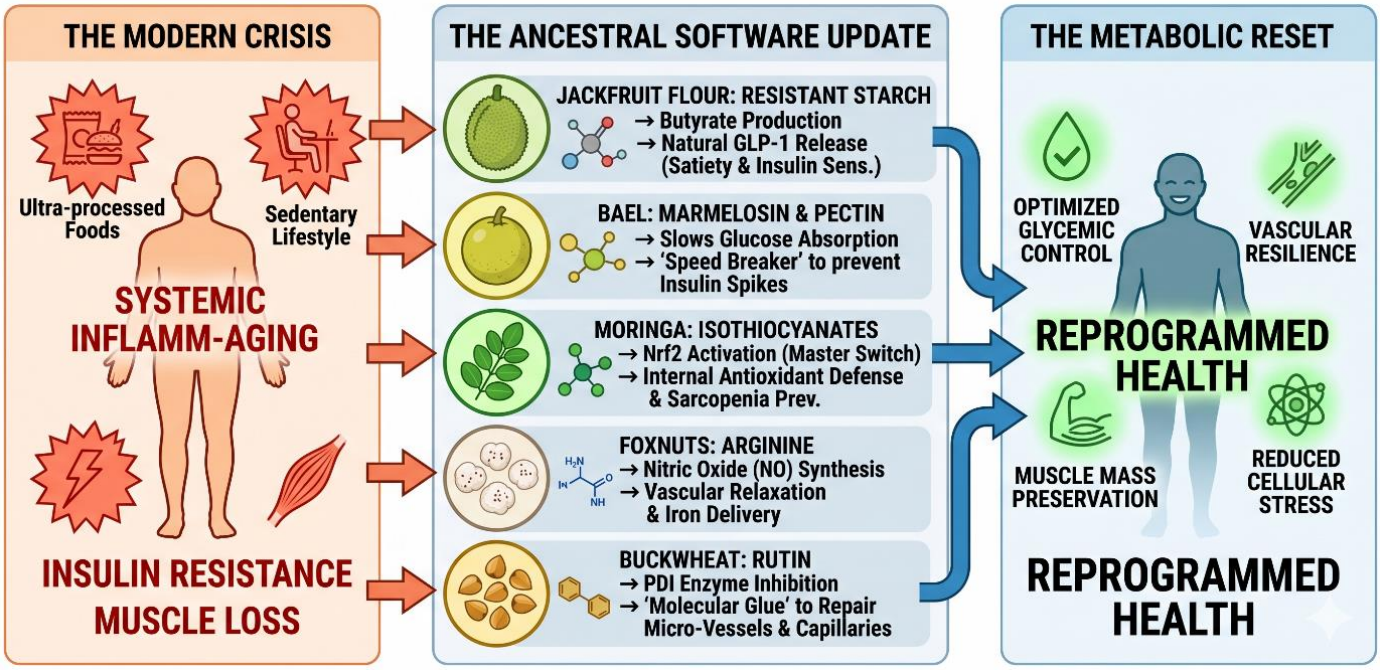


Figure 1- The Indigenous Reset: From Evolutionary Mismatch to Reprogrammed Health

A comprehensive visual summary of the systems Biology approach. It depicts the flow from modern metabolic stressors (Inflammaging) through the indigenous "Ancestral Software Update" intervention, resulting in the optimized physiological state of metabolic resilience and cellular homeostasis.

This has led to the "Modern Malnutrition Paradox": we are overfed but starving at a cellular level. We are witnessing "Inflamm-aging"a state where the body is in a constant, low-grade simmer of inflammation, leading to anaemia, brain fog, and "lifestyle" diseases.

The solution isn't a new drug; it's an Ancestral Bio-hack. We are rediscovering "Orphan Crops" that act as molecular remote controls, turning off disease genes and turning on health genes through a process called Nutri-metabolomics. By reintroducing these, we initiate a "Metabolic Reset" at the mitochondrial level, ensuring our internal hardware finally recognizes the nutritional software we are providing.

Table 1: Bioactive Profiles and Clinical Targets of Indigenous Five

Food Item	Primary Bioactive	Scientific Target	Clinical Outcome (2026 Trend)
Jackfruit	Resistant Starch Type-2	SCFAs / Butyrate Production	Reduced HbA1c & Insulin Resistance
Bael	Marmelosin / Pectin	α-glucosidase inhibition	Gut Microbiome Diversification
Moringa	Isothiocyanates	AMPK Activation	Muscle Preservation (Sarcopenia)
Foxnuts	Arginine / Glutamine	Nitric Oxide Synthesis	Cardio-Vascular Stability
Buckwheat	Rutin / D-chiro-inositol	PDI Enzyme Inhibition	Micro-vascular (Capillary) Repair

The Anti-Diabetic Architecture: The Glycaemic Shield

In the world of metabolic health, "speed" is the enemy. When sugar hits your blood like a tidal wave, it damages your organs. We need a "speed breaker," and nature has provided two masterpieces that physically and chemically re-engineer our digestion.

Unripe green jackfruit acts as the ultimate "cellular bodyguard." It is packed with Type-2 Resistant Starch (RS2). While most starches turn into sugar in your stomach, RS2 "resists" digestion and travels all the way to your colon. Think of this as a "fibre bodyguard" for your bloodstream. Once in the colon, it ferments to produce Butyrate, which binds to specific receptors (GPR41/43) that trigger the natural release of GLP-1—the same hormone targeted by modern weight-loss medications. Replacing just two spoons of wheat flour with jackfruit flour is like installing a "security guard" at the gates of your metabolism, signalling your brain to feel full while telling your liver to stop producing excess sugar.

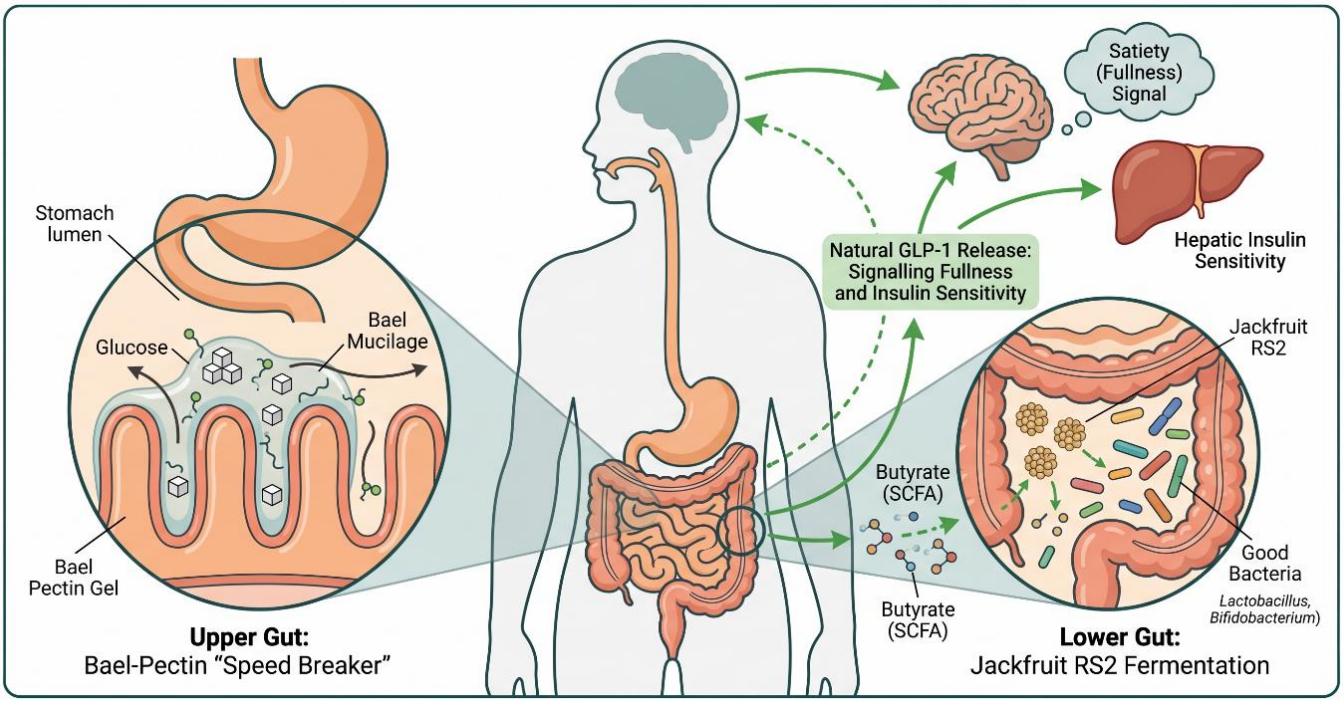


Figure 2: The Bio-Symptomatic Architecture of Gut-Brain Axis Modulation

This figure illustrates the mechanical and hormonal journey of the "Glycaemic Shield." It highlights the localized entrapment of glucose by Bael mucilage in the upper gut and the distal fermentation of Jackfruit RS2 into short-chain fatty acids (Butyrate), which triggers the systemic endocrine release of GLP-1.

Wood Apple (Bael) complements this by acting as a "Natural Speed-Breaker." Famous for its sticky mucilage, Bael's true power lies in Marmelosin, a bioactive molecule that physically sits on the enzymes meant to break down carbohydrates. Bael turns a dangerous "sugar spike" into a manageable "sugar stroll." It creates a thick, protective gel in your stomach that ensures energy is released slowly over hours, preventing the "Glucotoxic Spike" that exhausts the pancreas. It essentially cleanses the intestinal lining like a "biological broom," sweeping away the inflammatory triggers of metabolic syndrome

Moringa & Foxnuts: The Precision Repair Duo

When fighting anaemia or managing weight, the body is under significant stress. You need high-performance building blocks to ensure you don't lose muscle while trying to lose fat.

Moringa Oleifera is a biological miracle, providing all nine essentials amino acids the "Lego blocks" of life in a ratio that mimics human protein. Beyond nutrition, it contains Isothiocyanates that activate the Nrf2 pathway, the body's "Master Antioxidant Switch." Most vitamins just provide temporary relief, but Moringa goes a step further by *teaching* your cells how to produce their own internal protection, such as Glutathione. It's like giving your body a "Self-Repair Manual" instead of just a temporary patch, ensuring that your cellular defence is always "on.".

Foxnuts (Makhana) provide the perfect cardio-metabolic balance through a unique Arginine-to-Proline ratio. Arginine is the mandatory substrate for Nitric Oxide (NO), a gas that relaxes your blood vessels. Think of your blood vessels as pipes; over time, they get stiff and narrow. The Arginine in Makhana acts as a "pipe cleaner," keeping your vessels flexible and wide. This is crucial for delivering iron to your cells and keeping your blood pressure in check. Simultaneously, its Proline content repairs the "glue" of your body's tissues, optimizing your vascular "pipes" and gut lining at the same time.

Buckwheat (Kuttu): The Micro-Vessel Mechanic

Buckwheat is often relegated to fasting rituals, but it is actually a high-performance "Vascular Mechanic" capable of repairing the microscopic damage caused by high blood sugar.

Its secret weapon is Rutin, a potent "capillary stabilizer." In diabetic states, tiny blood vessels often become "leaky" and inflamed; Rutin acts as a molecular "sealant" for these leaks by inhibiting the enzymes that cause dangerous micro-clots. If your arteries are the highways, your capillaries are the small side-streets. Buckwheat ensures these side-streets stay paved and open, which is the only way nutrients and oxygen can reach your skin, eyes, and brain. Furthermore, it contains D-chiro-inositol, a rare molecule that acts as a "spare key" to let glucose into your cells even if the main "insulin key" is broken, bypassing insulin resistance entirely.

Synergy in Practice: The "Metabolic Chrono-Plate"

To get the most out of these "software updates," we must align them with our body's internal 24-hour clock, or **Chrono-nutrition**.

Mealtime	The "Desi" Plate	The Scientific Synergy
Breakfast (7-9 AM)	Buckwheat & Moringa Crepe	**Vascular Priming:** Waking up the blood vessels with Rutin and activating cellular defence with Nrf2.
Lunch (1-2 PM)	Jackfruit-fortified Roti/Rice	**The Insulin Buffer:** Using the "Resistant Starch shield" to dampen the sugar response of the day's heaviest meal.
Evening (5-6 PM)	Roasted Makhana (Foxnuts)	**The Heart Relaxer:** Using Arginine to dilate vessels and support recovery after the day's stress.
Bedtime (9-10 PM)	Warm Bael Infusion	**The Gut Reset:** Feeding the "good" bacteria to repair the gut lining and reduce inflammation overnight.

Conclusion: From Tradition to Prescription

The most advanced nutrition in 2026 isn't coming from a laboratory—it's coming from our heritage. As a PhD scholar, my research proves that "Grandma was right," but for sophisticated molecular reasons she couldn't see. We aren't just eating these foods because they are traditional; we are eating them because they are Molecular Technologies. By choosing Jackfruit, Bael, Moringa, Makhana, and Buckwheat, you are taking back "Molecular Sovereignty." You are choosing to feed your body a language it understands—one that fixes the "software mismatch" of the modern age. It's time to move beyond the medicalization of our plates and embrace the evidence-based power of indigenous crops to reprogram our health from the inside out.

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Application of Chromatographic and Mass Spectrometric Approaches in Plant Tissue Culture

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Mohini Natha[1], Kinjal Bhutka[2], Dr. S. R. Vyas[3]

[1]Young Professional- 1, Department of Biotechnology and Tissue Culture Laboratory, Bioscience Research centre, Sardarkrushinagar Dantiwada Agricultural University.

[2]Research Associate, Department of Biotechnology and Tissue Culture Laboratory, Bioscience Research centre, Sardarkrushinagar Dantiwada Agricultural University.

[3]Unit Heat, Bioscience Research centre, Sardarkrushinagar Dantiwada Agricultural University.

Abstract

Plant tissue culture is a well-established biotechnological tool used for plant propagation, conservation, and genetic improvement. However, its efficiency is often constrained by variable regeneration responses and strong genotype dependence. A major factor influencing in vitro success is the endogenous biochemical status of explants, particularly phytohormones and secondary metabolites. Advanced analytical platforms such as high-performance liquid chromatography (HPLC), gas chromatography–mass spectrometry (GC–MS), and liquid chromatography–tandem mass spectrometry (LC–MS/MS) have enabled highly accurate profiling of these compounds. Studies indicate that regeneration potential is closely associated with internal hormonal balance, especially auxin–cytokinin ratios, abscisic acid levels, and stress-associated metabolites. These analytical approaches provide a biochemical foundation for selecting responsive explants and improving culture conditions.

Keywords: Plant tissue culture, phytohormones, secondary metabolites, chromatography, mass spectrometry.

Introduction

Plant tissue culture plays a central role in plant biotechnology, particularly in micropropagation, germplasm conservation, and the production of secondary metabolites (George et al., 2008). Despite its broad applications, regeneration efficiency remains inconsistent due to inherent physiological differences among explants. Conventional protocols largely focus on optimizing external growth regulators, often without fully considering the internal biochemical state of the tissue.

In vitro developmental responses are primarily regulated by endogenous phytohormones, including auxins, cytokinins, abscisic acid, gibberellins, jasmonates, and salicylic acid, which collectively control cell division, differentiation, and stress adaptation (Skalický et al., 2018). Alongside these hormones, secondary metabolites such as phenolics and flavonoids contribute to cellular redox balance and influence reprogramming during culture initiation. The levels of these compounds vary depending on the explant source, developmental stage, and physiological age.

Younger meristematic tissues generally exhibit higher concentrations of growth-promoting hormones, whereas mature tissues tend to accumulate abscisic acid, which suppresses regenerative capacity. LC–MS/MS-based studies further demonstrate that hormonal profiles shift significantly during tissue maturation, with a decline in growth regulators and a rise in stress-related metabolites (Novák et al., 2017). These variations strongly influence the regenerative potential of different explant types.

Chromatographic and Mass Spectrometric Profiling

Chromatographic techniques such as HPLC, GC, and UPLC are widely used for the separation and quantification of plant hormones due to their precision and reproducibility. HPLC is particularly effective for polar phytohormones like cytokinins and indole-3-acetic acid (IAA), while GC–MS is more suitable for volatile or derivatized compounds such as gibberellins and abscisic acid (Jorge et al., 2016).

Mass spectrometry, especially LC–MS/MS, has significantly advanced hormone analysis by enabling sensitive, simultaneous detection of multiple phytohormones in complex biological matrices. It provides accurate quantification based on mass-to-charge ratios and fragmentation patterns (Novák et al., 2017). Together, these approaches have revealed that plant growth and development are regulated by interconnected hormonal networks rather than isolated signals (Urano et al., 2017).

Chromatographic profiling has also established a clear relationship between auxin–cytokinin balance and successful callus induction and organogenesis (Skalický et al., 2018), offering a biochemical basis for optimizing culture media formulations.

Secondary Metabolites in Tissue Culture Systems

Secondary metabolites such as phenolics, flavonoids, and lipid-derived compounds play a significant role in regulating morphogenesis, signaling pathways, and oxidative stress responses. Elevated phenolic accumulation may lead to tissue browning and reduced regeneration efficiency, whereas controlled levels often support embryogenic competence (Salem et al., 2020).

Flavonoids are known to influence auxin transport by modulating transporter activity, thereby affecting developmental patterning during in vitro regeneration (Jorge et al., 2016). In addition, LC–MS-based metabolomic studies have shown that lipid signaling molecules contribute to somatic embryogenesis and stress adaptation.

By integrating chromatographic and mass spectrometric profiling, it becomes possible to identify metabolically favorable explants and fine-tune culture conditions, including growth regulator balance, nutrient composition, and elicitor treatments. Such adjustments have been shown to significantly enhance secondary metabolite accumulation in vitro (Salem et al., 2020; Wang et al., 2020).

Integrated Analytical Approach for Culture Optimization

The integration of chromatographic and mass spectrometric techniques has transformed plant tissue culture into a more predictive and evidence-based system. LC–MS-based metabolomics allows simultaneous profiling of hormones and metabolites, offering a comprehensive biochemical snapshot of explant physiology (Salem et al., 2016).

Regeneration efficiency is closely associated with a balanced auxin–cytokinin ratio, regulated abscisic acid levels, and optimal secondary metabolite composition. This biochemical insight enables the selection of highly responsive explants and supports rational optimization of culture conditions based on measurable internal parameters rather than empirical adjustments (Wang et al., 2020).

Conclusion

Chromatographic and mass spectrometric techniques have significantly improved the understanding and optimization of plant tissue culture systems. These methods allow precise characterization of endogenous hormones and secondary metabolites, revealing that regeneration is governed by complex and interconnected biochemical networks. Their application supports predictive explant selection and data-driven optimization of culture conditions, ultimately improving the efficiency and reliability of plant tissue culture systems.

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Bold, Shy, or Brave: Personality in the World of Insects

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Kota Sahithi Chowdary[1], Repaka Harika[1], Gopu Sushma[2]
[1]Ph. D Scholar, Indira Gandhi Krishi Vishwavidyalaya, Raipur.
[2]Ph. D Scholar, Professor Jayashankar Telangana Agricultural University.

Abstract
Recent research in behavioural ecology suggests that insects, despite their small and simple nervous systems, exhibit consistent individual differences in behaviour, a phenomenon commonly referred to as "animal personality." Studies across multiple taxa—including ants, bees, fruit flies, and spiders—demonstrate variation in boldness, activity, aggression, and exploration that remains stable over time and contexts. These behavioural patterns are influenced by both genetic and environmental factors and can have profound implications for colony dynamics, survival strategies, and evolutionary fitness. This article synthesizes current evidence on insect personality, explores underlying mechanisms, and discusses its ecological and evolutionary significance.

Introduction
Personality has traditionally been studied in humans and vertebrates, often associated with cognition and complex social interactions (Gosling, 2001). However, accumulating evidence suggests that even invertebrates, particularly insects, exhibit consistent behavioural differences. Understanding insect personality can shed light on the evolution of behaviour, social organization, and ecological adaptation in small-brained organisms.

Defining Personality in Insects
Behavioural ecologists define personality as **consistent inter-individual differences in behaviour across time and contexts** (Reale *et al.*, 2007). In insects, this can include:

1. **Boldness:** willingness to explore novel environments or take risks
2. **Activity:** general movement levels or foraging effort
3. **Aggressiveness:** response to competitors or predators
4. **Sociability or exploratory behaviour:** tendency to interact with conspecifics or investigate new stimuli

These traits are measurable in laboratory and field studies, often using repeated trials to confirm stability over time.

Evidence from Insect Studies
Ants and Bees: Studies on honeybees and ants demonstrate that individual workers show **consistent differences in risk-taking and foraging behaviour**. Bold individuals tend to lead exploration or scouting, while cautious workers prioritize nest defense (Pinter-Wollman et al., 2013). These differences are critical for **colony efficiency** and survival under fluctuating environmental conditions.

Fruit Flies: *Drosophila melanogaster* is a model system for examining the genetic and environmental basis of personality. Some flies display consistently high levels of activity and exploration, while others are more cautious (Kain *et al.*, 2012). The stability of these behaviours over time supports the presence of measurable personality traits even in insects with tiny neural circuits.

Spiders and Solitary Insects: Research on solitary spiders and beetles shows that **boldness and aggressiveness** vary among individuals and predict hunting efficiency and survival (Sih *et al.*, 2004). This suggests that personality traits are **not confined to social insects**, but may be a widespread adaptive feature among invertebrates.

Mechanisms Behind Insect Personality
1. Genetic Influences: Selective breeding experiments in fruit flies and social insects indicate a heritable component of activity and risk-taking behaviour (Kain *et al.*, 2012).

2. Environmental Effects: Early-life experiences, social interactions, and resource availability can modulate behavioural traits (Pinter-Wollman *et al.*, 2013).

3. Neurochemical and Physiological Factors: Variation in neurotransmitters such as dopamine and octopamine has been linked to exploratory and aggressive tendencies in insects (Barron *et al.*, 2015).

Ecological and Evolutionary Significance

Insect personalities are not just curiosities—they influence **fitness, survival, and social structure**:

1. Colony Dynamics: In social insects, the balance of bold and cautious individuals can improve task allocation and foraging efficiency.

2. Predator-Prey Interactions: Variation in risk-taking may affect survival probability and vulnerability to predation.

3. Evolutionary Implications: Personality traits can be subject to natural selection, maintaining diversity in behavioural strategies within populations.

Conclusion

Personality is a meaningful concept in insects, demonstrating that complex behavioural variation does not require a large brain. From ants to fruit flies, consistent differences in boldness, activity, and aggression influence individual fitness and social organization. Recognizing these traits not only deepens our understanding of insect ecology but also challenges assumptions about the relationship between brain size and behavioural complexity.

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Mirid Bugs: The Double Agents of Agriculture

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Repaka Harika[1], Kota Sahithi Chowdary[1], Gopu Sushma[2]
[1]Ph. D Scholar, Indira Gandhi Krishi Vishwavidyalaya, Raipur.
[2]Ph. D Scholar, Professor Jayashankar Telangana Agricultural University.

Abstract
Mirid bugs (family *Miridae*) are among the most dynamic insect groups in agricultural ecosystems, acting both as destructive pests and beneficial predators. Their omnivorous feeding behavior, adaptability, and rapid evolutionary responses have made them increasingly important in modern agriculture. Recent breakthroughs in genomics, chemical ecology, and climate-based modeling have revealed new insights into their biology and management. This article explores the fascinating dual nature of mirid bugs and highlights cutting-edge research shaping their future control.

Introduction
In agriculture, insects are often classified as either harmful or beneficial. However, mirid bugs challenge this simple distinction. With over 11,000 species worldwide, they are one of the largest families of true bugs and are found in almost every terrestrial ecosystem. Their success lies in their remarkable adaptability and feeding flexibility, allowing them to thrive under changing agricultural conditions. Recent studies show that mirid bugs are becoming dominant in many cropping systems due to ecological shifts caused by modern farming practices (Xu et al., 2023).

Who are Mirid Bugs?
Mirid bugs, commonly called plant bugs, are small (3–10 mm), soft-bodied insects that are often green or brown, blending easily with vegetation. A key identifying feature is the triangular "cuneus" on their forewings. Unlike typical sap-sucking insects, mirids possess a unique feeding system that allows them to exploit both plant and animal food sources.

A Unique Feeding Strategy
Mirid bugs use a lacerate-and-flush feeding mechanism, where they puncture plant tissues and inject digestive enzymes. These enzymes liquefy plant cells, which are then sucked up by the insect. This feeding behavior: causes tissue necrosis, leads to yellowing and deformation, damages flowers and fruits. It also activates plant defense pathways linked to jasmonic acid and ethylene signaling (Ratnadass & Deguine, 2020).

The Dark Side: Mirid Bugs as Pests
Several species, such as *Apolygus lucorum* and *Adelphocoris suturalis*, are major agricultural pests. They feed on over 200–270 host plants, cause severe damage in cotton, vegetables, and fruits and reduce both yield and market quality. Their rapid reproduction and ability to develop resistance to insecticides have made them increasingly problematic (Xu et al., 2023).

The Bright Side: Natural Pest Controllers
Despite their harmful effects, many mirid bugs are beneficial predators. For example: *Nesidiocoris tenuis* controls whiteflies and aphids and *Cyrtorhinus lividipennis* suppresses rice planthoppers. These species are important components of biological control programs. However, their plant-feeding habit means their benefits depend on ecological conditions.

Recent Scientific Breakthroughs
Recent research has revolutionized our understanding of mirid bugs, revealing why they are so successful and how they can be managed more effectively.

1. Genomics and Molecular Adaptation: Advanced genome sequencing has uncovered the genetic basis of mirid adaptability. One of the most important breakthroughs is the development of chromosome-scale genome assemblies of mirid bugs such as *Adelphocoris suturalis*. These studies revealed: Expansion of detoxification gene families (e.g., cytochrome P450s, GSTs, carboxylesterases), Genetic basis of insecticide resistance, Genes linked to omnivorous feeding behavior. This genomic evidence explains how mirid bugs can adapt quickly to pesticides and diverse host plants, making them highly resilient pests (Xu et al., 2023).

2. Chemosensory Evolution and Feeding Flexibility: Recent transcriptomic studies (2025) have uncovered large repertoires of odorant-binding proteins (OBPs) and chemosensory proteins (CSPs) in mirid bugs. Over 140 OBPs and ~70 CSPs identified leads to differences between predatory vs plant-feeding species and plays key role in host detection and

prey selection. These results suggest that changes in chemosensory genes played a major role in the evolution of omnivory in mirid bugs (Sun et al., 2025).

3. Advanced Pheromone Biology: A major breakthrough (2024–2025) is the discovery of new pheromone receptor lineages in mirid bugs i.e., Identification of novel receptor genes sensitive to key pheromone compounds, evidence that mirids evolved two distinct pheromone detection systems, high sensitivity to compounds like *(E)-2-hexenyl butyrate*. This discovery is crucial because it enables development of: pheromone traps, behavioral disruption techniques, eco-friendly pest control strategies (Zhang et al., 2025).

4. Plant Volatiles and Host Selection: Mirid bugs rely heavily on plant volatile compounds to select hosts. Recent findings show: Different crop varieties emit different chemical signals and some plants attract mirids, while others repel them. This knowledge can be used to develop: Resistant crop varieties and Push–pull pest management systems (Wu et al., 2024).

5. Genetic Engineering for Plant Defense: A cutting-edge breakthrough involves genetic manipulation of plant defense pathways. Engineering cotton to produce higher levels of DMNT (a defensive volatile), increased resistance against mirid bugs and enhanced attraction of natural enemies (indirect defense). This demonstrates how biotechnology can create crops that actively defend themselves against mirid pests (Teng et al., 2024–2025).

6. Climate-Based Pest Prediction: Recent ecological studies have integrated climate data with pest population dynamics. Strong correlation between temperature, humidity, and mirid population peaks, peak infestation occurs during flowering and reproductive stages and development of forecasting models for early warning systems. These models help farmers predict outbreaks and apply timely control measures (Pandey et al., 2025).

7. Evolutionary Insights: Phylogenetic studies reveal that mirid bugs evolved alongside flowering plants and developed mixed feeding habits over time. This evolutionary flexibility explains their success in modern agroecosystems.

Why are Mirid Bugs Increasing?

The rise of mirid bugs is linked to: Adoption of Bt crops, reduced use of broad-spectrum insecticides, climate change, intensive monocropping. These changes have allowed mirids to occupy ecological niches previously dominated by other pests.

A Delicate Balance: Pest or Beneficial?

Mirid bugs are neither entirely harmful nor beneficial. Their role depends on: Population density, availability of prey and crop stage. When prey is abundant, they act as predators. When prey is scarce, they switch to plant feeding, causing damage. This behavioural plasticity makes them difficult to manage.

Management Strategies (Modern Approach)

1. Ecological Management:

a. Conservation of natural enemies
b. Habitat diversification

2. Behavioral Control: Pheromone-based monitoring and trapping

3. Host Plant Resistance: Breeding crops with unfavorable volatile profiles

4. Integrated Pest Management (IPM): Combining biological, cultural, and chemical methods.

Modern research strongly supports IPM as the most sustainable strategy.

Conclusion

Mirid bugs truly live up to their title as the “double agents of agriculture.” Their ability to switch between beneficial and harmful roles makes them both fascinating and challenging. Recent scientific breakthroughs have revealed that their success is rooted in genetic adaptability, chemical communication, and ecological flexibility. Future pest management will rely on precision agriculture, biotechnology, and ecological balance, rather than heavy chemical use. Understanding mirid bugs is not just important—it is essential for sustainable agriculture.

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Circular Agriculture through Vermi Wash: The Future of Low-Cost Organic Agriculture

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Hasim Kamal Mallick[1], Disharee Nath[2]

[1&2]Researcher, Institute of agricultural science, University of Calcutta, 51/2 Hazra Road, Kolkata-700019.

Introduction

The growing pressure on natural resources and increasing environmental concerns have made it necessary to shift from conventional linear agriculture to more sustainable circular systems. Circular agriculture focuses on reusing organic waste as valuable inputs, reducing dependency on external resources while improving overall system efficiency. In this context, vermitechnology, particularly vermiwash production, has gained attention as a practical and cost-effective approach in organic farming. This approach aligns with eco-friendly strategies that convert agricultural waste into useful resources, thereby promoting sustainability and environmental conservation (Mallick, 2024).

Vermiwash is a liquid obtained during the vermicomposting process when water passes through organic material inhabited by earthworms. As it moves through the compost, the water collects various substances such as nutrients, enzymes, plant growth regulators, and beneficial microorganisms released by earthworms. This results in a biologically active solution that plants can easily absorb. Because of this property, vermiwash is widely used as both a foliar spray and a soil application to enhance plant growth.



Fig2:Prepared vermiwash

Research has shown that vermiwash contributes to improved seed germination, stronger root systems, better vegetative growth, and increased crop yield. In addition to its role as a fertilizer, it also helps protect plants by reducing the impact of pests and diseases, due to the presence of natural antimicrobial and antifungal compounds. This reduces the need for chemical inputs and supports safer agricultural practices.

Another important advantage of vermiwash is its affordability and ease of production. It can be prepared using locally available organic waste with minimal infrastructure, making it especially beneficial for small-scale farmers. By converting waste into a useful agricultural input, vermiwash supports the core idea of circular agriculture and promotes environmentally friendly farming, consistent with sustainable waste recycling approaches reported in recent studies (Mallick *et al.*, 2025).

Overall, the use of vermiwash represents a step toward more sustainable and regenerative agricultural systems, offering a simple yet effective solution for low-cost organic farming.

Table 1: Composition of vermiwash and its benefit (taken from Gudeta *et al.*, 2021):

Contents of vermiwash	Benefit of vermiwash	References
Decomposer bacteria	Suppress pathogen	(Mondal *et al.*, 2015)
Hormones (Cytokines, auxin)	Facilitate plant root and shoot growth	(Das *et al.*, 2014)
Amino acid and mucosal secretion	Suppress pathogen and pest	(Liu *et al.*, 2004)
Vitamins	Facilitates growth and development of plant	(Tripathi *et al.*, 2005).
Phosphatase	Stabilize physical, chemical and biological properties of soil as well suppress pathogen and solubilize phosphorus	(Gosh *et al.*, 2018)
Actinomycetes	Suppress pathogen	(Tripathi *et al.*, 2005; Balachandar *et al.*, 2018)

Amylase, cellulase	Stabilize physical, chemical and biological properties of soil as well applied in carbon turnover by degrading organic matter	(Das *et al.*, 2014; Tripathi *et al.*, 2005)
Varieties of micronutrients Ni, Mg, Fe, Ca, K	Facilitate the growth and productivities of plant	(Ndegwa and Thompson, 2000)

Vermi Wash

Vermiwash is a collection of excretory products and mucus secretions of earthworms along with dissolved micronutrients derived from decomposed organic matter.

Table2: characteristics of Vermiwash standard report published by (Nayak *et al.*, 2019)

Physical/chemical characteristics	Vermi wash
pH	7.42
EC (dsm^{1})	1.47
Total Organic Carbon (%)	0.005
Nitrate (NO3) (%)	0.007
Phosphorus (P2O5) (%)	1.49
Potassium (K2O) (ppm)	24.0
Calcium (ppm)	2.0
Magnesium (ppm)	136.0
Iron (ppm)	0.06
Zinc (ppm)	0.02
Copper (ppm)	0.01
Nickel (ppm)	0.06
Lead(ppm)	0.02
Nitrobacter spp. (CFU/ml)	1.12x103
Total Fungus (CFU/ml)	1.45x103

Method of Preparation

1. Take one big bucket and one mug.
2. Set up one stopcock on the lower most part of the bucket.
3. Put a layer of broken brick pieces of stones having thickness of 10-15 cm in the bucket.
4. Over this layer put another layer of sand having thickness of 10-15 cm.
5. Then put a layer partially decomposed cow dung having 30-45 cm thickness over it.
6. Then put another layer of soil having 2-3 cm thickness.
7. Now open the stop cock of the bucket and water the materials taken in the bucket.
8. Then put 100-200 nos. of earthworms in the bucket.
9. After that, a layer of paddy straw having 6 cm thickness is given.
10. Now open the stopcock of the bucket and spray water regularly for a period of 7-8 days.
11. After 10 days the liquid Vermiwash will be produced in the bucket.
12. Hang one pot with a bottom hole over the bucket in such a way so that water falls drop by drop.
13. Every day 4-5 liters of water is to be poured in the hanging pot.
14. Keep another pot below the stopcock to collect the Vermiwash. Everyday 3-4 litres of liquid Vermiwash can be collected.

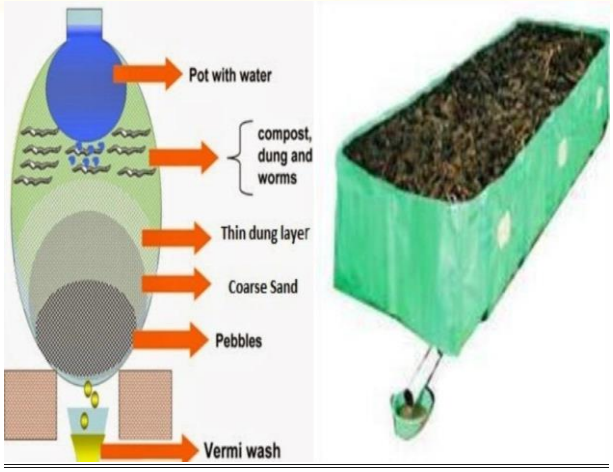


Fig 3: methods of vermiwash preparation (Source: https://share.google/fRS997PioK2aXIW7z)

Table3: Application Methods and Recommended Dosage of Vermiwash in Crop Production:

Method of Application	Dilution	Mode of Application	Agronomic Benefits
Root / Shoot Dip	1:5 (Vermiwash: Water)	Seedlings or cuttings are immersed for 15-20 minutes prior to transplantation	Enhances root initiation and improves early plant establishment
Foliar Spray	1:5 (Vermiwash: Water)	Sprayed on both upper and lower leaf surfaces	Improves nutrient absorption, promotes growth, and reduces disease incidence
Soil Drench	1:10 (Vermiwash: Water)	Applied directly to soil around plant roots	Controls soil-borne pathogens due to antimicrobial properties
Soil Application	Variable (diluted)	Applied to soil during crop growth	Enhances nutrient availability and soil fertility
Growth Promoter (Vermiwash alone)	1 L in 20 L water	Applied as foliar spray (3-4 times during crop cycle)	Stimulates plant growth and increases yield
Growth Promoter (with Cow Urine)	0.5 L Vermiwash + 0.5 L Cow urine in 20 L water	Mixed and sprayed on crops	Provides synergistic effect for enhanced growth
General Spray	1:7-10	Sprayed on leaves, preferably in the evening	Improves plant vigor and productivity
Disease Control Mixture	1 L Vermiwash + 1 L Cow urine + 10 L water	Mixed, kept overnight, and sprayed (50-60 L per bigha)	Effective in controlling crop diseases and improving plant health

Role of Vermi Wash in Circular and Sustainable Agriculture

Vermiwash plays an important role in circular agriculture by converting organic wastes into a nutrient-rich liquid input that supports sustainable crop production. It is produced when water passes through vermicompost containing earthworms, utilizing materials such as animal dung, crop residues, and kitchen waste, thereby reducing waste accumulation and recycling nutrients within the system. Vermiwash is considered a storehouse of macro- and micronutrients, enzymes, vitamins, amino acids, plant growth regulators, and beneficial microorganisms, which together enhance seed germination, root development, and overall plant growth. Its application has been reported to improve plant height, leaf area, flowering, fruit yield, and even the nutritional quality of crops. In addition to promoting growth, vermiwash also acts as a natural plant protectant. The presence of bioactive compounds and microbial populations helps suppress pests and diseases, reducing the need for chemical fertilizers and pesticides. It further contributes to soil health by increasing microbial activity, improving organic carbon content, and enhancing soil physicochemical properties, which support long-term fertility and nutrient availability. As an inexpensive and easily prepared input, vermiwash effectively links waste recycling with crop production, making it a key component of circular agriculture and a practical solution for sustainable and low-cost organic farming systems.

Summary and Conclusion

Vermiwash has emerged as an important input in sustainable agriculture due to its ability to convert organic waste into a nutrient-rich liquid that supports plant growth and soil health. Produced through the action of earthworms on organic materials, it contains essential nutrients, growth-promoting substances, and beneficial microorganisms that improve seed germination, root development, and overall crop performance. Its use through different application methods such as foliar spray, soil drenching, and root dipping has shown positive effects on yield as well as plant health.

In addition to its role as a biofertilizer, vermiwash also helps in reducing pest and disease problems because of its natural antimicrobial properties. This reduces the dependence on chemical fertilizers and pesticides, making farming practices safer and more environmentally friendly. Its preparation is simple, low-cost, and based on locally available organic waste, which makes it especially useful for small and marginal farmers.

Our future depends on how we take care of our environment today. If we protect our environment, it will continue to give us what we need. At Last, our environment is our future. By respecting and caring for it, we ensure a sustainable and thriving world for ourselves and generations to come. Let us commit to making responsible choices today for a better tomorrow. Our actions today will shape the legacy we leave behind.

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Farmers' and Traders' Participation in the e-National Agriculture Market in Andhra Pradesh

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Soumya P[1], M. Srikala[2]

[1]Institute of Agribusiness Management and [2]Department of Agricultural Economics, ANGRAU-S. V. Agricultural College, Tirupati, Andhra Pradesh, India.

Introduction

Agricultural markets in India have undergone several reforms aimed at improving market accessibility, promoting transparency in market operations, and ensuring fair prices for farmers for their produce (Bandhavya *et al*. 2022). The Agricultural Produce Market Committee (APMC) Act, implemented during the colonial era, established a series of state-owned wholesale marketplaces, regulated agricultural marketing in India (Gautam *et al*. 2023). There are currently 7,190 regulated wholesale markets in India that are governed by this Act (Kumar *et al*. 2020). The main idea behind APMCs was to provide farmers a forum for marketing their products, thereby reducing exploitation by traders. Unfortunately, the APMC system suffered a noticeable decline over time because of vested interests, shortsighted policy formulation, and bureaucratic flaws (Saha *et al*. 2023). Even though agriculture and agricultural marketing are state subjects, the Government of India decided to integrate all the nation's existing APMC marketplaces into a single electronic platform to establish a national agriculture market (e-NAM) (Reddy and Kumar 2023). In order to benefit farmers and other agri-marketing industry stakeholders, related issues such as states fragmenting into multiple market areas overseen by APMCs, various and numerous levy structures, multiple license requirements for trading across different mandis, high net worth bidder interventions in price-fixing, inadequate infrastructure facilities to reach mandis, and non-usage of e-bidding technology, problems of information dissemination causing asymmetry, lack of transparency in price discovery, high market charges, movement controls between state to state, etc. should be prioritized (Bathla and Hussain 2022; Gautam *et al*. 2022). e-NAM is considered a suitable solution to the issues and challenges that the current Agri-marketing system stakeholders are facing. As of now, 1522 APMCs from 23 states and 4 union territories are connected to the e-NAM network and in Andhra Pradesh, 33 APMCs are connected.

e-trading was launched in ten markets in Andhra Pradesh in October, 2015 with financial support of Rs. 3.60 crores from the Indian government. e-NAM has been introduced in 12 marketplaces under the National Agricultural Market with the Agri Tech Infrastructure Fund Scheme (ATIF). The State government established an online marketing system wherein licenced dealers from all over the nation would bid for the stocks to guarantee transparent price discovery for farm commodities (Raju *et al*. 2016). At present, 3,964 traders and 14.54 lakh farmers were enrolled on the e-NAM network in Andhra Pradesh. Participation of farmers and traders in e-NAM is influenced or inhibited by numerous factors. The primary goal of the current study is to discover these factors through the personal interview method.

Factors Influencing Farmers' and Traders' Participation in e-NAM

Time-saving operation: Farmers as well as traders opined that marketing through the e-NAM system is a time-saving operation.

Realization of best price: Most of the farmers felt that e-NAM facilitated them to realize a better price without any malpractices.

Fewer chances for rejection: As the produce is tested for quality and certified by the market committees at the assaying lab, the farmers feel that there is little chance for the traders to reject the produce based on quality.

Reduction of malpractices: As the entire trading process is online and transparent, farmers thought that there might be a reduction in malpractices.

Accurate weighing process: Almost all the farmers felt that the weighing of the produce is accurate due to the introduction of electronic weigh bridges and scales under e-NAM.

Quick payment: The farmers were convinced by the early payment of money after selling their produce through the e-NAM platform.

Factors Inhibiting Farmers and Traders from Participating in e-NAM

Non-participation of farmers directly in trade: During the interaction with the farmers, it was observed that the farmers are not directly participating in online trade and the entire process is taking place through commission agents, as they provide loans to the farmers whenever they need money for the farm operations. So, the farmers will not directly participate in trading through e-NAM. The amount taken as a loan would be deducted by the commission agents at the time of final payment. The farmers are also interested in getting paid as soon as the sale of produce is completed, and

traders might not be in a situation to pay. So, the commission agent will pay the farmer and in turn, he will get paid in 15 to 21 days. So, the commission agent obtains a fee from farmers for carrying on the entire process. Officially, these charges would be 1 to 4 per cent, but unofficially, it might be somewhat higher.

Internet connectivity: Internet connectivity is also a major problem in many market yards. The entire trading process in e-NAM is online. So, the internet is a must for marketing commodities through e-NAM.

Lack of trust of traders in quality certificates: Many traders opined that they would purchase the produce only after physical examination and they cannot trust the quality certificate issued by the assaying lab, which has become a major constraint for inter-state trading. Particularly in turmeric, there is a lack of equipment in the assaying lab for testing the curcuminoid content. In the Guntur market, the quality assaying lab is well equipped, but due to the presence of a large number of lots during peak season, it is practically impossible to test each and every sample.

Difficulty in understanding the norms of e-NAM: As most of the farmers in the villages are illiterate, they have expressed difficulty in understanding the norms of e-NAM.

Ignorance of farmers regarding the benefits of e-NAM: As most of the farmers are not involved directly in e-NAM, they are not aware of the benefits of trading in e-NAM.

Difficulty in handling online transactions: Most of the farmers felt that they are facing hurdles with the online transaction of money, as the money credited into their bank accounts is being directly debited towards their loan dues and they have to travel around 20 kms to reach the nearest bank in case of any issues.

Strategies Need to be Formulated

1. Farmers should be initiated to participate in trade and guidance should be provided by the APMC officials through the entire process of e-NAM.

2. Need for provision of better internet facilities to the farmers and traders who participate in e-NAM trade in APMCs.

3. There should be provision of training to traders on the process of assaying in laboratories and the generation of a quality certificate.

4. Farmers should be given training on the entire e-NAM process to understand the norms of e-NAM. If the farmer is illiterate and unable to understand the process of e-NAM, then the e-NAM personnel should carry out the entire trading process on behalf of the farmer.

5. Farmers should be educated regarding the price they will be receiving by selling the produce through e-NAM by comparing it with the channels where e-NAM is not involved.

6. The government should provide training to farmers regarding the online transaction of money. This training can be provided by bank personnel.

7. The government should bring more stringent norms so that the traders can complete the payment within 1or 2 days.

8. e-NAM employees should initiate the traders to participate in online trade not only in the APMC nearest to them but also in APMCs farther from them.

Conclusion

e-NAM represents a major reform in India's agricultural marketing system by improving transparency, price discovery, and market access. Major factors influencing farmers' and traders' participation in e-NAM were time-saving operations, realization of the best price for the produce, and fewer chances for rejection. The factors also include the reduction of malpractices, an accurate weighing process and quick payment. Whereas factors that inhibit farmers' and traders' participation in e-NAM were internet connectivity, lack of trust of traders in the quality certificate, difficulty in understanding the norms of e-NAM, ignorance of farmers regarding the benefits of e-NAM and Difficulty in handling online transactions. The government should focus on improving infrastructure, strengthening assaying systems, providing training and awareness, ensuring timely payments, and encouraging direct farmer participation. Addressing these challenges is essential for e-NAM to function as an efficient and inclusive national agricultural market.

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Moringa Leaf Powder: Nutritional Profile and Diverse Applications

Article ID: 73595

Anindita Karmakar[1]

[1]Department of Post Harvest Engineering, Faculty of Agricultural Engineering, BCKV, Mohanpur, 741252, West Bengal, India.

Abstract

Moringa oleifera, commonly known as the drumstick tree, is a highly valuable plant due to its nutritional, medicinal and industrial significance. Often called a "miracle tree," its leaves, pods, seeds and roots have multiple uses. The leaves are especially rich in vitamins A, C, and E, essential minerals and protein, making them beneficial in combating malnutrition. They can be consumed fresh, dried or powdered and are widely used in food products. Moringa also possesses antioxidant, anti-inflammatory and antimicrobial properties, supporting its role in managing blood sugar, cholesterol and immunity. India is the largest producer, contributing about 2.6 million tonnes annually and meeting nearly 80% of global demand. However, despite widespread consumption of pods, awareness of the nutritional benefits of moringa leaves remains limited, highlighting the need for greater promotion of their use.

Keywords: *Moringa oleifera*, Antioxidant properties, Medicinal uses, Malnutrition, Nutritional awareness.

Introduction

Moringa oleifera, commonly referred to as the drumstick tree, is considered one of the most valuable plants worldwide due to its extensive nutritional, medicinal and industrial applications. It is often called a "miracle tree" because nearly all parts of the plant—leaves, pods, seeds, and roots—have practical uses. One of the primary advantages of moringa lies in its remarkable nutritional profile. The leaves are rich in vitamins such as A, C and E, along with essential minerals including calcium, iron and potassium. They also provide a significant amount of protein, making moringa leaf an excellent dietary option, particularly in regions affected by malnutrition. The leaves can be consumed fresh, dried or in powdered form and are commonly incorporated into soups, curries, and nutritional supplements. Moringa is also well known for its therapeutic properties. It contains potent antioxidants that help protect the body from various diseases. Regular intake of moringa leaves may assist in regulating blood sugar levels, lowering cholesterol and enhancing immune function. Additionally, it is believed to exhibit anti-inflammatory and antimicrobial activities, contributing to its widespread use in traditional medicine. Beyond its health-related benefits, moringa has several practical and industrial applications. The seeds are used in water purification processes, as they aid in removing impurities and microorganisms. Oil extracted from the seeds is widely utilized in cosmetics and skincare products due to its moisturizing and anti-aging characteristics. Moringa also holds significant importance in agriculture and environmental management. It grows rapidly, requires minimal water and can thrive in nutrient-poor soils, making it a suitable crop for arid regions (Salsi et al., 2025). It is also used as animal feed and contributes to improving soil fertility.

India is the largest producer of moringa, with an annual production of approximately 2.6 million tonnes of fruits from an area of 43,600 hectares, resulting in a productivity of about 63 tonnes per hectare (Samsai, 2023). Among the different states, Tamil Nadu ranks first in both area and production, followed by Andhra Pradesh and Karnataka. India is the principal supplier of moringa globally, accounting for around 80% of global demand. Although moringa pods are widely consumed, there remains a considerable lack of awareness among the general population in India about the exceptional nutritional value of its leaves. While it is commonly recognized as a backyard vegetable, its potential as a "miracle leaf" rich in concentrated vitamins and minerals is not widely understood.

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Preparation of Moringa Leaf Powder

The preparation of moringa leaf powder from Moringa oleifera involves a series of controlled processing steps aimed at preserving its nutritional and functional quality. Fresh, healthy leaves are first harvested and separated from stems, followed by thorough washing with potable water and mild sanitizing solutions to remove adhering contaminants and reduce microbial load. The cleaned leaves are then drained and subjected to drying, which is a critical step influencing the final product quality. Shade drying or low-temperature tray drying (40–50°C) is generally recommended to minimize the degradation of heat-sensitive nutrients such as vitamin C and chlorophyll. Drying is continued until the moisture content is reduced to approximately 5–7%, ensuring extended shelf life and preventing microbial spoilage. The dried leaves are subsequently ground using suitable milling equipment to obtain a fine powder, typically in the range of 60–100 mesh size, and sieved for uniformity. The powder is then packed in moisture-proof, airtight containers and stored under cool, dry and dark conditions to maintain stability during storage. At an industrial scale, additional operations such as mechanical leaf stripping, conveyor-based washing and advanced drying techniques—including solar drying, hot air drying, and freeze drying—may be employed to improve efficiency and product quality. Proper control of processing

parameters such as temperature, air velocity and drying duration is essential to achieve high-quality moringa powder with desirable physicochemical and nutritional attributes.

Nutrients Present in Moringa Leaf Powder

Moringa leaf powder is widely regarded as a highly nutrient-dense functional food because of its abundant content of macronutrients, micronutrients and bioactive compounds. On a dry weight basis (per 100 g), it generally provides about 250–320 kcal of energy and contains a high protein level of approximately 24–27%, making it an important plant-based protein source. Carbohydrates account for around 28–38%, while dietary fiber ranges between 11–19%, supporting digestive health. The fat content is comparatively low (5–10%) and is mainly composed of beneficial unsaturated fatty acids. The proximate composition of fresh leaves, dry leaves and leaf powder is presented in Table1.

Table1. Proximate composition of fresh leaves, dry leaves and leaf powder (Islam et al., 2021):

Nutrients (g/100gm)	Fresh leaves	Dry leaves	Dry leaf powder
Protein	6.7	29.4	27.1
Fats	1.7	5.2	2.3
Carbohydrate	12.5	41.2	38.2
Fiber	0.9	12.5	19.2

With respect to micronutrients, moringa powder is particularly rich in minerals such as calcium iron, potassium, magnesium and phosphorus, all of which are essential for bone health, oxygen transport and various metabolic processes. It also serves as a valuable source of vitamins, especially vitamin A, vitamin C, vitamin E and B-complex vitamins including thiamine and riboflavin. Furthermore, moringa leaf powder contains considerable amounts of carotenoids, polyphenols and other antioxidants that contribute to its anti-inflammatory effects and overall health-promoting potential. However, different drying methods influence the amount of nutrient in the final dried powder. Table 2 summarizes the effect of some common drying methods on the nutrient content moringa leaf powder.

Table 2. Effect of drying methods on nutrient content of moringa leaf powder (Kaushik and Verma, 2024):

Methods of Drying	Vitamin-A (mg/100 g)	Ascorbic Acid (mg/100 g)	Iron (mg/100 g)	Zinc (mg/100 g)	Total chlorophyll (mg/100 g)
Natural drying (Sun drying) of moringa leaves	5.20	126.18	27.21	3.48	500.45
Natural drying (Shade drying) of moringa leaves	5.75	155.80	27.18	3.44	550.46
Hot air oven drying of moringa leaves at 50 °C	5.59	115.38	27.88	3.77	629.65
Hot air oven drying of moringa leaves at 60 °C	5.39	110.77	27.90	3.80	615.78
Microwave oven drying of moringa leaves at 300W + 40 °C	5.70	106.12	27.56	3.59	605.46
Microwave oven drying of moringa leaves at 450W + 40 °C	5.58	104.32	27.57	3.62	580.27
Tray drying of moringa leaves at 50 °C	6.20	112.45	28.03	3.80	630.24
Tray drying of moringa leaves at 60 °C	5.55	109.78	28.05	3.81	620.61

Uses of Moringa Leaf Powder

Moringa leaf powder has a wide range of applications due to its high nutritional value and the presence of diverse bioactive compounds. It is commonly used as a dietary and nutritional supplement to enhance nutrient intake and can be incorporated into smoothies, juices, soups, curries and bakery products. Owing to its high content of proteins, vitamins, minerals, and antioxidants, it is particularly effective in combating malnutrition and promoting overall health. In addition to its nutritional applications, moringa leaf powder is widely recognized for its medicinal and therapeutic uses. It possesses strong antioxidant, anti-inflammatory, antimicrobial, and antidiabetic properties and is often consumed to help regulate blood glucose levels, lower cholesterol and strengthen immune function. These properties make it highly valuable in traditional as well as modern herbal medicine.

Moringa leaf powder is also extensively utilized in the cosmetic industry. It is incorporated into skincare and haircare formulations such as face masks, scrubs, and hair packs due to its antioxidant and nourishing properties, which help protect the skin from oxidative damage and improve hair health (Patel et al., 2026). Moringa leaf powder also serves as a nutrient-rich supplement in animal feed, improving growth performance, milk yield and overall health in livestock and

poultry. In the agricultural sector, moringa leaf powder and its extracts are used as plant growth promoters and natural fertilizers, contributing to enhanced crop productivity and soil fertility (Abdulazeez et al., 2024).

Conclusion

Moringa oleifera stands out as a highly versatile and valuable plant with significant contributions across nutritional medicinal, industrial, and agricultural domains. The transformation of its leaves into powder through carefully controlled processing techniques ensures the preservation of its rich nutrient profile, including proteins, vitamins, minerals and bioactive compounds. Drying methods and processing conditions play a crucial role in determining the quality and nutrient retention of the final product. Moringa leaf powder, with its high nutritional density and functional properties, serves as an effective dietary supplement and holds promise in addressing malnutrition and promoting overall health. Additionally, its wide-ranging applications in medicine, cosmetics, animal nutrition and agriculture highlight its economic and industrial importance. Therefore, the proper processing, utilization and promotion of moringa leaf powder can contribute significantly to food security, sustainable agriculture and improved public health.

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Insects at the Urban Fringe: Rethinking Peri-Urban Farming Ecosystems

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Gopu Sushma[1], Repaka Harika[2], Kota Sahithi Chowdary[2]
[1]Ph. D Scholar, Professor Jayashankar Telangana Agricultural University, Hyderabad.
[2]Ph. D Scholar, Indira Gandhi Krishi Vishwavidyalaya, Raipur.

Abstract
Peri-urban agriculture, located at the interface of rural and urban systems, plays a vital role in food security and livelihoods under rapid urbanization. These systems support diverse insect communities, including pests, pollinators, and natural enemies, whose dynamics are strongly influenced by urban factors such as warming, pollution, habitat fragmentation, and artificial lighting. Such conditions often lead to increased pest outbreaks and ecological imbalance. Case studies from Indian regions, including Bengaluru, Hyderabad, Delhi and Chennai, highlight these challenges and responses. Sustainable management approaches such as habitat enhancement, biological control, and technological tools are essential. Insects in peri-urban systems serve as indicators of ecological health and resilience.

Introduction
On the outskirts of every growing city lies a silent transition zone that is neither fully rural nor completely urban. These are the landscapes of peri-urban agriculture, where vegetable fields, poultry units and small farms coexist with highways, housing colonies and industrial units. While these farms are crucial for feeding expanding urban populations, they also host a dynamic and often overlooked community, the insects.

Global estimates suggest that there are currently 67 million ha of urban croplands and that urban farms, which are particularly prevalent in East and South Asia and the Global North, may already account for approximately 5.9% of all cropped areas around the world. It was found that over 260 million urban households may engage in food production around the world (Hamilton *et al.*, 2014). Though urban farms tend to be small-scale and labour intensive, there is increasing evidence to suggest that small farms can be equally, if not more productive than large-scale industrial monocultures (Grafius *et al.*, 2020). Farms smaller than 2 ha make up just 12% of global agricultural areas, yet produce 70% of food in Africa and Asia, demonstrating the importance of small farms to food security (Lowder *et al.*, 2016). Understanding insects in these systems is not just about pest control, it's about managing a fragile ecological balance shaped by rapid urbanization.

Peri-Urban Farming
Peri-urban agriculture refers to farming practices carried out on the fringes of cities, where land, water, and labor compete with urban demands. These areas are highly dynamic, constantly changing under the pressure of urban expansion and environmental stress. Unlike rural farms, peri-urban systems are deeply integrated with urban ecosystems. They recycle waste, supply fresh produce, and act as ecological buffers, but they also face pollution, habitat fragmentation, and resource scarcity and insects respond to all of this quickly.

Importance of Peri Urban Farming
With rapid urbanization, peri-urban agriculture is becoming essential for food security and sustainability. It provides fresh produce, reduces transport costs and supports livelihoods especially in developing countries. But its success depends on maintaining ecological balance.



Changing rainfall patterns have led to more frequent flooding in the north Indian city of Gorakhpur, which has involved citizens to come up with nature-based solution peri urban farming to build resilience.

Insect Diversity in Peri Urban Lands

Although urbanization has also contributed to biodiversity loss in its own right, paradoxically, urban areas have been shown to support surprisingly diverse, abundant and intact insect communities. In fact, the abundance and diversity of insect fauna visiting urban gardens and street trees have been observed to approach, and even exceed, numbers in adjacent wild land. This is likely because cities, unlike intensive agricultural systems, can contain exceptionally rich small patches of flowering plants, resulting in a high degree of plant species diversity within properties between properties and in aggregate across the city. Moreover, urban areas appear to provide a diversity of substrates that are otherwise rare in agricultural settings. In addition, urban areas have higher abundance and diversity of pollinators compared to adjoined agricultural areas and at least in one E.U. study, higher rates of pollinator visitation to crops growing on peri-urban farms (Ploessl *et al.*, 2024).

Peri-urban farms often support surprisingly rich insect biodiversity. Studies have recorded hundreds of species across functional groups such as herbivores, predators, pollinators, and decomposers. Similarly, research from India shows that even highly human-influenced peri-urban landscapes can support diverse butterfly populations, highlighting their role in conservation. These insects fall into three broad categories:

1. **Pests** – aphids, whiteflies, borers *etc* damaging crops
2. **Beneficial insects** – predators like ladybird beetles and parasitoids
3. **Pollinators** – bees, butterflies, hoverflies.

Urban Effects on Insect Behavior

Peri-urban environments create unusual conditions that directly affect insect ecology:

Warmer microclimates: Cities generate heat, raising temperatures in surrounding areas. This accelerates insect metabolism and reproduction, leading to faster pest outbreaks.

Pollution stress: Air and soil pollution weakens plants, making them more vulnerable to insect attacks.

Artificial lighting: Streetlights and buildings interfere with nocturnal insect behavior, affecting feeding, mating, and migration patterns.

Fragmented habitats: Natural habitats are broken into small patches, reducing populations of beneficial insects that naturally control pests.

Pest Outbreaks in Peri-Urban Areas

In peri-urban systems, pest outbreaks can be more frequent and severe due to several reasons
1. Continuous cropping provides year round food
2. Reduced natural enemies due to habitat loss
3. Overuse of pesticides disrupting ecological balance.

Case Studies from India

1. Fall Armyworm in South India: The invasion of Fall Armyworm in maize fields around cities like Bengaluru highlighted how peri-urban systems can accelerate pest spread.

a. Continuous maize cultivation around urban markets created ideal conditions
b. Warmer temperatures supported rapid reproduction
c. Farmers initially relied heavily on pesticides, leading to resistance concerns

2. Vegetable farms around Hyderabad: Peri-urban vegetable belts supplying leafy greens to Hyderabad face chronic whitefly and aphid infestations.

a. Heavy pesticide use reduced populations of natural predators
b. Residue concerns became a public health issue due to proximity to urban consumers

3. Pollinator decline near Delhi: Rapid urbanization around Delhi has led to a noticeable decline in pollinators in peri-urban farms.

a. Habitat loss and air pollution affected bee populations
b. Reduced pollination impacted yields in crops like cucurbits

4. Butterfly diversity in Northeast peri-urban landscapes: Studies in peri-urban regions of Northeast India show that despite human disturbance, these areas can support rich butterfly diversity.

a. Mixed land use created varied microhabitats
b. Low-intensity farming helped maintain ecological balance

5. Urban waste and pest breeding in Chennai: In peri-urban Chennai, improper waste disposal near farms created breeding grounds for flies and other pests.

a. Organic waste attracted insect populations.
b. Increased pest pressure on nearby vegetable farms.

Ecological Opportunities for Management of Pest Problem at the City Edge

Despite the challenges, peri-urban farming also offers unique opportunities for sustainable insect management. It is important for us to understand not just how to control insects, but how to coexist with them in a rapidly changing world.

Habitat creation: Small interventions like planting flowering borders or hedgerows can restore beneficial insect populations.

Pollinator support: Urban proximity allows for awareness campaigns and community involvement in protecting pollinators.

Waste-based systems: Organic waste from cities can support insect-based innovations (like composting and bio-conversion), linking agriculture with circular economy models.

Smart and Sustainable Solutions

Technology is increasingly helping farmers tackle insect challenges:

1. Mobile apps for pest identification
2. Sensor-based pest monitoring
3. Precision spraying techniques

Combined with ecological knowledge, these tools form the backbone of **sustainable pest management strategies**.

Conclusion

Peri-urban agriculture is a frontline system in the fight for food security. Peri-urban farms are more than food-producing units, they are living laboratories of ecological change. Insects here are early indicators of environmental stress, adaptation, and resilience. But its success depends on how well we understand and manage insect populations. Managing them requires a shift in thinking: from eradication to balance, from chemicals to ecology, from short-term control to long-term sustainability. The case studies show that insects are not just problems, they are indicators of ecological health. As cities continue to expand, the future of farming may well depend on how wisely we manage these tiny yet powerful inhabitants at the urban edge.

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Next-Generation Millets: Unlocking the Potential of Microgreens

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Vikash[1], Vinitha K[1], Vasanthasri J[1], Yamavathi V[1], Geethanjali S[2], Jayadevi S[2]
[1]IV BSc (Hons.) Agriculture.
[2]Assistant Professor (Biochemistry), Department of Crop Physiology & Biochemistry,
[2]Project Associate, Department of Crop Physiology & Biochemistry,
Anbil Dharmalingam Agricultural College and Research Institute, Trichy.

Introduction

For millennia, millets have been the backbone of subsistence farming across Asia and Africa. These small seeded grasses cultivated since the Neolithic era were prized for their resilience and ability to thrive in marginal soils with minimal rainfall. Yet, with the Green Revolution of the 20th century, millets were relegated to the status of "coarse grains" or "famine foods," displaced by subsidized rice and wheat. The tide is now turning. The United Nations' declaration of 2023 as the International Year of Millets catalyzed a global movement to reintegrate these nutritional powerhouses into mainstream diets. Governments, nutritionists, and agricultural scientists are championing millets as a solution to dual crises: climate change and malnutrition. But the millet renaissance is not merely about returning to traditional porridges and flatbreads. Innovation is required to meet the needs of modern urban consumers who demand convenience, taste, and concentrated nutrition. Enter millet microgreens the juvenile stage of the millet plant, harvested just days after germination. Microgreens occupy a unique space between sprouts and mature greens. They have gained immense popularity over the past decade, with crops like broccoli, radish, and sunflower dominating the market. However, millet microgreens remain an underexplored frontier. This article argues that millet microgreens represent the "next generation" of millet utilization offering superior nutritional bioavailability, rapid cultivation cycles, minimal resource inputs, and unparalleled culinary versatility.



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Types of Millets

Millets are broadly classified into two categories based on their cultivation scale, geographical distribution, and grain size: major (macro) millets and minor (micro) millets. Both categories produce viable microgreens, though each offers unique flavor profiles and nutritional nuances.

1. Major Millets (Macro Millets): These are the most widely cultivated and commercially traded millets. They have larger grain sizes and are grown across extensive areas. Ex. Sorghum, Pearl Millet, and Finger Millet.

2. Minor Millets (Micro Millets): These are often referred to as "small millets." They are typically grown in specific ecological niches and possess distinct nutritional advantages. Ex. Foxtail, Little, Kodo, Proso, Barnyard millet.

Why Microgreen Millets Surpass Whole Millet Grains?

While whole millet grains are undeniably nutritious, the microgreen stage offers distinct advantages that make them a superior functional food.

1. Nutritional Bioavailability: During germination, seeds undergo a process of metabolic activation. Enzymes break down complex compounds leading to reduction of anti-Nutrients such as phytic acid, tannins, and enzyme inhibitors which bind minerals and reduce absorption are significantly lowered during sprouting and early growth, Vitamins A, C, E, and

K increase dramatically. For instance, finger millet microgreens have been shown to contain up to 5× more vitamin C than the mature grain.

2. Concentrated Nutrient Density: Because microgreens are harvested at an early stage, they pack a high density of nutrients per gram. A 100g serving of millet microgreens can deliver comparable or higher levels of iron, calcium, and antioxidants than 200–300g of cooked whole millet.

3. Rapid Growth and Resource Efficiency: A millet crop takes 80–120 days to mature. Millet microgreens are ready in 7–14 days, allowing for continuous production with minimal land, water, and energy inputs.

Nutritional Comparison of Whole Millet Grain Vs. Millet Microgreens

Nutrient (per 100g fresh weight)	Whole Finger Millet (Cooked)	Finger Millet Microgreens (Raw)	Difference
Energy (kcal)	120	35	Lower calories
Protein (g)	3.5	4.2	↑ 20%
Dietary Fiber (g)	3.8	4.5	↑ 18%
Calcium (mg)	86	210	↑ 144%
Iron (mg)	1.5	3.8	↑ 153%
Vitamin C (mg)	0	25	New source
Vitamin A (IU)	0	1800	New source
Antioxidants (ORAC value)	300	1200	↑ 300%



Cultivation Methods for Millet Microgreens

Millet microgreens can be grown through several methods, ranging from simple home setups to commercial hydroponic operations. Each method influences yield, quality, and scalability.

1. Soil-Based Cultivation (Traditional): This is the most accessible method for home growers and small-scale farmers.

Step	Description
Seed Selection	Use untreated, organic millet seeds. High germination rate (>90%) is critical.
Growing Medium	Shallow trays (10×20 inches) filled with 1–2 inches of organic potting mix or coco peat.
Sowing	Spread seeds densely (approx. 1–2 oz per tray). Lightly press into soil without burying.
Germination	Mist with water, cover with a humidity dome or another tray for 2–3 days to retain moisture. Keep in indirect light.
Growth Phase	After germination, remove cover and place in bright, indirect sunlight or under grow lights (12–16 hours daily). Water gently once or twice daily.
Harvest	Harvest at 7–14 days when the first true leaves emerge. Cut just above the soil line using clean scissors.

2. Hydroponic and Soilless Cultivation: For commercial scalability and urban farming, hydroponic systems offer significant advantages:no soil-borne diseases, reduced water usage (up to 90% less than soil), and consistent yields.




Culinary Applications Bringing Millet Microgreens to the Table

One of the greatest strengths of millet microgreens is their versatility. Unlike whole millets, which require cooking and often cultural familiarity, microgreens integrate seamlessly into contemporary cuisine.

Application	Description
Fresh Salads	Use as a base (like lettuce) or as a nutrient-dense topping. Pair with citrus vinaigrette to complement the sweet-grassy flavor.
Smoothies & Juices	Blend a handful with banana, spinach, and coconut water. The mild flavor does not overpower fruit-based smoothies.
Sandwiches & Wraps	Replace lettuce or alfalfa sprouts for a crunchier, more nutritious layer.
Pesto & Sauces	Blend with basil, garlic, nuts, and olive oil to create a unique millet-green pesto.



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Sustainability and Economic Potential

Millet microgreens align with several Sustainable Development Goals (SDGs), including Zero Hunger (SDG 2), Good Health and Well-being (SDG 3), and Responsible Consumption and Production (SDG 12).

1. **Environmental Advantages:**
   - **Water Efficiency:** Hydroponic millet microgreens use up to 90% less water than field-grown grains.
   - **Land Use:** Vertical cultivation allows production in non-arable urban spaces, reducing pressure on natural ecosystems.
   - **Carbon Footprint:** Local production eliminates transportation emissions associated with imported greens.
2. **Economic Opportunities:**
   - **Low Entry Barrier:** Small-scale microgreen farming requires minimal capital investment ($200–500 for basic home setup).
   - **High Value:** Millet microgreens retail at $20–40 per kilogram, compared to $1–3 per kilogram for whole millet grains.
   - **Short Cash Cycle:** Harvest every 10–14 days enables consistent revenue streams for urban farmers and entrepreneurs.

Conclusion

The journey of millets from ancient staples to marginalized crops, and now to reimagined super foods reflects a broader shift in how we approach food systems. Millet microgreens represent the next logical step in this evolution. They retain the climate resilience and nutritional heritage of traditional millets while adapting to the demands of modern urban life: convenience, taste, and concentrated functional benefits .By harnessing simple yet innovative cultivation methods from soil-based trays to hydroponic vertical farms we can democratize access to this nutritionally dense food. For health-conscious individuals, millet microgreens offer a potent tool for managing blood sugar, improving iron status, and supporting overall wellness. For entrepreneurs and farmers, they represent a high-value, low-barrier entry into the growing functional foods market. For the planet, they offer a model of sustainable, resource-efficient agriculture.

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Influence of Altitude on Fruit Quality of Temperate Fruits: Mechanisms, Evidence, and Lessons from Kinnaur

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Arun Kumar[1]
[1]Scientist, Fruit Science, Krishi Vigyan Kendra Kinnaur, Sharbo, Rekong Peo.



High-altitude cultivation of temperate fruits like apple, pear, peach, plum, walnut, and apricot, consistently yields produce of exceptional quality. The superior attributes of such fruit, including intense colouration, robust sugar–acid balance, firm texture, thick cuticle, and enriched phytochemical composition, are not accidental but are the product of a precise ensemble of environmental stimuli that operate more powerfully at elevation. Kinnaur district of Himachal Pradesh, spanning altitudes of roughly 1,500 m to over 3,500 m above mean sea level, represents one of India's most compelling illustrations of this relationship. This article reviews the physiological and biochemical mechanisms by which altitude enhances fruit quality and draws upon evidence from research and field observations, with particular emphasis on conditions prevailing in Kinnaur.

Introduction

Among the many factors that determine the quality of temperate fruits, the altitude at which an orchard is situated holds a place of singular importance. Growers and traders across mountain regions have long recognised that fruits harvested from higher belts command premium prices, attract discerning buyers, and arrive at markets with a visual and sensory appeal that lower-altitude produce rarely matches. What folklore and commercial experience have long affirmed, science has progressively explained through studies of plant physiology, biochemistry, and agroecology. Kinnaur, situated along the upper Satluj, Baspa, and Spiti river valleys in the trans-Himalayan and sub-alpine zones of Himachal Pradesh, is one such region where altitude and fruit quality intersect most visibly. The district hosts a remarkable altitudinal gradient that accommodates apple (*Malus x domestica*), pear (*Pyrus communis*), peach (*Prunus persica*), apricot (*Prunus armeniaca*), plum (*Prunus domestica*), walnut (*Juglans regia*), and cherry (*Prunus avium*). Orchards in the Nichar, Sangla Valley, Kalpa, and Pooh belts demonstrate systematically how rising elevation translates into improved fruit attributes, deeper colour, crisper flesh, longer shelf life, and a flavour complexity that has become the hallmark of Kinnaur produce. This article synthesises the scientific evidence on altitude-driven fruit quality enhancement, interprets it in the context of Kinnaur's unique agro-climatic conditions, and highlights the specific physical and biochemical traits, including the often-overlooked thickened cuticle, that distinguish fruit from the higher reaches.

Kinnaur's Agro-Climatic Profile: A Natural Laboratory

Kinnaur's climate is shaped by its position in the rain shadow of the Greater Himalaya and its exposure to the continental high-pressure systems of Central Asia. The district receives limited monsoon precipitation, typically between 250 and 800 mm annually in the main fruit-growing belts, with the bulk of moisture coming as snowfall in winter. Summers are bright and dry, with long hours of sunshine and low relative humidity. Winters are severe, providing the extended chilling hours that temperate fruit crops require for breaking dormancy and flowering uniformly. The key agro-climatic characteristics that give Kinnaur its qualitative edge are as follows. First, mean summer temperatures in orchards situated between 2,000 m and 3,200 m rarely exceed 28°C, with cool nights that regularly dip to 8–12°C even in July and August. This pronounced diurnal temperature variation often 15–20°C between day and night is perhaps the single most important driver of fruit quality in the district. Second, solar radiation intensity is substantially higher than in lowland regions because of cleaner, thinner air and reduced cloud cover, exposing fruit to elevated levels of photosynthetically active radiation (PAR) and ultraviolet-B (UV-B) energy. Third, the growing season, though shorter in calendar terms, is characterised by a slow, deliberate maturation that allows full development of sugars, acids, aromatic compounds, and pigments. Fourth, the dry atmosphere and cold winters suppress many fungal pathogens and insect pest populations, reducing disease incidence and pesticide load on the fruit. Together, these conditions create what may be described as a quality environment, one in which every major environmental variable operates in a direction that favours superior fruit attributes.



Apple



Pear



Plum



Walnut



Nectarine



Apricot

Thermal Regime and Diurnal Variation: The Foundation of Flavour

Temperature governs virtually every aspect of fruit development. The rate of cell division, carbohydrate metabolism, organic acid synthesis, pigment accumulation, and the softening of flesh are all temperature-dependent processes. At high altitudes, the cool overall temperatures slow each of these processes, but it is the diurnal temperature variation the amplitude of the day–night cycle that most powerfully shapes fruit quality. During the day, warm temperatures and high irradiance drive photosynthesis, generating carbohydrates that are translocated to the developing fruit. At night, when temperatures drop sharply, the respiratory breakdown of these carbohydrates is curtailed because enzymatic activity is suppressed by cold. The net effect is an accumulation of sugars, primarily sucrose, fructose, and sorbitol in apple and pear, that is greater than what occurs in warmer, more equable climates. Studies on Fuji apple across an elevational gradient from 1,375 m to 1,715 m have confirmed that fruit hardness, total anthocyanin content, redness index, and sugar–acid ratio all increase progressively with altitude, while titratable acidity decreases to more palatable levels. In Kinnaur, apples from the Sangla Valley and higher Kalpa belt grown at 2,400–2,800 m exhibit this effect strikingly. The diurnal swing of 15–18°C during August and September coincides with the final stage of fruit swell and colour break, precisely when anthocyanin synthesis is most sensitive to thermal signals. The result is the intensely flushed, aromatic apple for which Kinnaur has become nationally known. Cool night temperatures also delay fruit senescence by slowing ethylene production, the hormone that triggers ripening. This delayed ripening extends the period over which flavour compounds develop, producing the complex aroma profiles, dominated by esters, alcohols, and aldehydes, that characterise well-matured mountain fruit.



Prune

Solar Radiation and UV-B Exposure: Colour and Chemistry

At the altitudes prevailing in Kinnaur's main fruit belts, the atmosphere is thinner, cleaner, and less obstructed by aerosols or industrial haze. Solar irradiance reaching the canopy is therefore substantially more intense than at lower elevations. Both the photosynthetically active component (PAR, 400–700 nm) and the ultraviolet portion (UV-B, 280–315 nm) of the solar spectrum are elevated, and each plays a distinct role in shaping fruit quality. UV-B radiation is a potent inducer of the flavonoid biosynthesis pathway. When fruit peel cells perceive elevated UV-B, they activate the expression of genes encoding chalcone synthase and other enzymes that lead to the production of anthocyanins, the pigments responsible for the red, pink, and purple hues of apple and plum peel. Research has demonstrated that colour coverage at harvest can exceed 90% at high-altitude sites compared to less than 50% at lower elevations for the same cultivar grown under otherwise similar conditions. This is not merely a cosmetic advantage; anthocyanins are potent antioxidants belonging to the flavonoid class, and their accumulation confers both nutritional and functional value to the fruit. PAR drives photosynthesis throughout the canopy, contributing to carbohydrate loading of the fruit. However, it also acts as a signal in fruit development light-exposed faces of apples in high-altitude Kinnaur orchards typically show far more intense colouration than shaded faces, a difference that becomes more pronounced as the elevation rises and ambient light intensity increases. The UV-B signal also stimulates the accumulation of a broader spectrum of phenolic compounds, including chlorogenic acid, catechins, quercetin glycosides, and cyanidin derivatives. These compounds serve as the plant's sunscreen and stress shield but simultaneously enrich the nutritional quality of the fruit, supporting its market value in health-conscious consumer segments.



Harvested apple fruits on plastic crates

Physical Quality Markers: Thick Cuticle, Firmness, and Storage Life

The Thick Cuticle: An Underappreciated Quality Trait: One of the most practically significant yet least publicised quality attributes of high-altitude fruit is the thickening of the epidermal cuticle. The cuticle is the outermost protective layer of the fruit skin, a composite structure of cutin polyester impregnated with waxes, both epicuticular (surface) and intra-cuticular. In fruit grown at high altitudes, this cuticle is measurably thicker and more densely waxed than in lowland-grown fruit of the same variety. The primary reason for cuticle thickening is the plant's adaptive response to the environmental stresses of altitude, intense UV radiation, low humidity, low ambient CO_2 partial pressure, and wide thermal fluctuations. The plant synthesises greater amounts of cutin and surface wax as a protective barrier against desiccation, UV penetration, and mechanical abrasion. In practical terms, this translates into several commercially important outcomes. A thicker cuticle dramatically reduces the rate of transpirational water loss from the fruit surface. This means that high-altitude Kinnaur apples shrivel far more slowly in storage than their lowland counterparts, retaining their crispness and turgidity during transport and shelf display. In a district where fruit must often travel considerable distances to reach markets in Shimla, Delhi, or even farther, this cuticle-mediated water retention is a genuine commercial asset. The wax layer also acts as a physical barrier against fungal spore germination and the penetration of pathogen hyphae into the fruit surface, contributing to lower post-harvest disease incidence. The characteristic bloom

or gloss on well-grown Kinnaur apple, visible even after gentle buffing is a direct expression of this wax deposition, and experienced traders use it as a proxy indicator of quality and provenance. Thick cuticles also confer greater resistance to russet formation and lenticel breakdown, both of which are post-harvest disorders that downgrade fruit appearance and marketability. In high-altitude conditions where calcium availability may be limited and rapid fluctuations in temperature and humidity occur, a robust cuticle provides mechanical and physiological buffering.

Fruit Firmness: Flesh firmness is a key determinant of consumer preference and post-harvest durability. High-altitude fruits are consistently firmer at harvest than those from lower elevations grown to the same maturity stage. This firmness arises from slower cell wall degradation, the enzymatic processes that loosen pectin and cellulose in the cell wall are retarded by cool temperatures and from the extended development period that allows more complete cell maturation. In Kinnaur, apple varieties such as Royal Delicious, Red Delicious, and Starking show markedly higher flesh firmness readings when grown above 2,200 m compared to orchards at 1,400–1,600 m. This firmness translates directly into a longer post-harvest life, reduced bruising during transport, and a satisfying crunch that consumers associate with fresh, high-quality fruit.

Reduced Sunscald and Surface Defects: Although high-altitude fruit is exposed to intense radiation, the accompanying low temperatures prevent the overheating of fruit surfaces that causes sunscald in warmer regions. The equilibrium between high light and cool air temperatures in Kinnaur's main fruit belts results in fruit that receives the colour-promoting benefits of UV-B exposure without the tissue damage associated with excessive heat accumulation in the pericarp.

Sugar–Acid Balance: The Chemistry of Flavour: The interplay of sugars and organic acids in fruit flesh is the biochemical basis of flavour. A fruit that is excessively sweet without adequate acidity is flat and cloying; one with high acidity and low sugar is harsh. The most prized fruits achieve a balance in which sucrose and fructose provide sweetness while malic acid (the dominant organic acid in apple, pear, and cherry) provides a refreshing sharpness that gives the palate a clean finish. Altitude acts on both sides of this equation. As described earlier, cool nights suppress respiration and allow greater sugar accumulation. Simultaneously, high-altitude conditions favour the retention of malic acid: cooler temperatures reduce the activity of malic enzyme, which normally converts malate to pyruvate during respiration, thereby preserving higher malic acid concentrations in the fruit at harvest. Comparative studies have shown that altitude positively correlates with sucrose, total sugar, and malic acid concentrations, while reducing glucose content and raising the sugar-acid ratio to levels preferred by consumers. For Kinnaur fruit, this manifests as the slightly tart, intensely aromatic character that distinguishes the district's apples and pears. Local varieties adapted to the highest reaches, where diurnal variation is greatest, often show the most pronounced expression of this balanced profile, and it is these traits that have driven the reputation of Kinnaur produce in premium markets.

Phytochemical Enrichment: Nutritional and Functional Value: Beyond the organoleptic qualities of colour, flavour, and texture, high-altitude cultivation enriches the nutritional and functional composition of fruit. The environmental stresses of altitude, elevated UV, cool temperatures, and periodic water deficit, act as stimuli for the biosynthesis of a wide range of secondary metabolites. These include phenolic acids (chlorogenic acid, caffeic acid), flavonols (quercetin and its glycosides), flavan-3-ols (catechin, epicatechin), and anthocyanins (cyanidin-3-galactoside in apple). These compounds serve protective roles in the plant, shielding tissues from UV damage, deterring herbivores, and managing oxidative stress. In the human diet, they function as antioxidants, anti-inflammatory agents, and potential modulators of chronic disease risk. High-altitude Kinnaur fruit is, therefore, not merely more attractive and better tasting but also nutritionally richer, a distinction increasingly valued by health-aware urban consumers and relevant for functional food positioning in export markets. The elevation of quercetin and chlorogenic acid content in high-altitude apple and walnut from Kinnaur has been noted in regional nutritional studies, though systematic multi-year quantitative data for the district remain an area requiring further research investment.

Reduced Pest and Disease Pressure: The cleaner, colder, and drier conditions of high-altitude Kinnaur orchards also confer an important indirect benefit to fruit quality: reduced pest and disease incidence. Several major fungal pathogens of apple and pear, scab (*Venturia inaequalis*), alternaria leaf spot (*Alternaria alternata* f.sp. mali), Premature leaf fall (*Marssonina coronaria*), powdery mildew (*Podosphaera leucotricha*), require warmth and humidity for spore germination and infection. At altitudes above 2,000–2,800 m in Kinnaur, the shorter warm season and low relative humidity substantially limit the development of these diseases, producing fruit with cleaner skin and lower pesticide residue loads. Similarly, insect pest populations including woolly apple aphid, San José scale, and codling moth are naturally suppressed by cold winters that reduce overwintering survival and by the abbreviated summer season that limits the number of pest generations per year. This ecological attrition of pest populations at altitude translates into fruit with fewer blemishes, lower pesticide inputs, and greater suitability for residue-sensitive export and premium domestic markets.

Summary: Altitude-Driven Quality Traits in Temperate Fruits

The following table summarises the primary altitude-driven environmental factors and their documented effects on temperate fruit quality, as evidenced by research and field observation from Kinnaur and comparable mountain agroecosystems.

Factor	High-Altitude Effect	Fruit Quality Impact
Cool nights & diurnal variation	Suppressed respiration; slow ripening	Higher sugar accumulation; superior flavour balance; firm texture
UV-B & PAR radiation	Upregulation of flavonoid pathway	Deep red colour; high anthocyanin; elevated antioxidant capacity
Thick cuticle (wax layer)	Adaptive response to UV, drought & cold	Reduced water loss; longer shelf life; disease resistance; market gloss
Malic acid retention	Cooler temperatures reduce malic enzyme activity	Refreshing acidity; complex, balanced flavour profile
Slow maturation period	Extended cell development phase	Greater firmness; full aroma development; nutritional richness
Elevated phenolics & phytochemicals	Stress-mediated secondary metabolism	Higher quercetin, chlorogenic acid, catechins; enhanced nutrition
Low pest & disease pressure	Cold winters; low humidity; short summer	Cleaner fruit; lower pesticide residue; export suitability
Low humidity & dry air	Reduced fungal infection pressure	Better storage quality; reduced post-harvest losses

Climate Change and the Upward Shift of Orcharding Zones

Kinnaur is not immune to the effects of a warming climate, and in some respects the district offers a window into the future of Himalayan horticulture. Reduced snowfall, erratic spring temperatures, and insufficient chilling accumulation in lower valleys have already begun to affect flowering regularity and crop set in the 1,200–1,800 m belt. In response, many growers are progressively moving operations to higher ground, to 2,400–2,800 m and beyond, where chilling hours remain adequate and summer temperatures have not yet reached disruptive levels. Research across Himachal Pradesh confirms that both cultivation area and productivity of apple are statistically linked to higher altitudinal zones, and that this upward migration has accelerated over the past two decades. For Kinnaur, where the topography accommodates this transition more readily than in many other districts, the shift to higher elevations offers not only a climate adaptation strategy but a quality upgrade, fruits from the uppermost orchards carry the most pronounced expression of altitude-driven quality traits. The district's position astride the 2,000–3,200 m altitudinal range means that Kinnaur is better insulated against climate disruption than lower-altitude apple-growing regions, and its quality premium may actually intensify as the climate warms.

Altitude, Quality, and the Case for Geographical Indication

The documented relationship between Kinnaur's altitude and the measurable, consistent superiority of its fruit provides a scientifically grounded basis for seeking Geographical Indication (GI) certification for district produce. GI status, which has already been awarded to Kinnaur apple under the GI Act, recognises that the quality and reputation of a product are essentially attributable to its geographical origin. The altitude-mediated quality traits reviewed in this article, cuticle thickness, anthocyanin content, sugar–acid balance, firmness, and phytochemical richness are precisely the kind of objectively demonstrable, origin-linked attributes that sustain GI claims. Kinnaur walnut and chilgoza pine nut offer analogous quality arguments, with the former being distinguished by its thin shell, plump kernel, and high oil quality, and the latter by its unique fatty acid profile and forest provenance at extreme altitude. Both crops merit systematic documentation of their altitude-driven quality credentials as part of future GI or premium branding initiatives.



Chiloza pine fruit

Conclusion

The influence of altitude on the quality of temperate fruits is neither incidental nor subtle; it is profound, multi-mechanistic, and increasingly well understood. For Kinnaur, elevation is the master variable that orchestrates every other quality determinant, from the anthocyanin-inducing chill of September nights to the UV-driven wax synthesis that gives the fruit its protective bloom. The thickened cuticle, intense colour, firm flesh, balanced sugar–acid profile, and elevated phytochemical composition of high-altitude Kinnaur fruit are the cumulative expression of a place, a climate, and an altitude working together in the service of quality. As the impacts of climate change continue to reshape fruit-growing geographies and as consumers grow more sophisticated in their appreciation of provenance-linked quality, the high-altitude orchards of Kinnaur are poised to occupy an increasingly important position in India's premium fruit economy. The task before researchers, extension workers, and policymakers is to document these quality advantages rigorously, communicate them effectively, and build the institutional frameworks, GI certification, quality grading, premium branding, that allow mountain growers to fully capture the value that nature and altitude have bestowed upon their produce.

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A Lion's Mane Mushroom {*Hericium erinaceus* (Bull.) Pers.}: A Comprehensive Scientific and Descriptive Study

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Abhinav Mishra[1], Alvee Patra[1], Shivani Kumari[1], Sahil Biswas[1], Vishal Rajvanshi[1], Shrvan Kumar[1]
[1]Rajiv Gandhi South Campus, Banaras Hindu University.

Abstracts

Hericium erinaceus (Lion's Mane) is a medicinal fungus native to the Northern Hemisphere, traditionally valued. Its contains polysaccharides and terpenoids (hericenones and erinacines) that stimulate nerve growth factor (NGF), offering potential neuroprotective, anti-inflammatory, and antioxidant benefits. Cultivating the mushroom on brown rice significantly increases the compound NDPIH, which enhances its anti-*Helicobacter pylori* activity while also enriching the substrate's protein and amino acid levels for use as a functional food. While long-term supplementation is linked to improved brain and gastrointestinal health, a single 3g dose in healthy young adults specifically improved psychomotor skills (manual dexterity) but did not produce immediate global effects on cognition or mood.

Keywords: *Hericium erinaceus* (Lion's Mane), Polysaccharides, Terpenoids and Nerve Growth Factor (NGF).

Introduction

Hericium erinaceus, popularly known as Lion's Mane, Monkey's Head, or Yamabushitake, is an edible and medicinal tooth fungus native to temperate forests in North America and Eurasia. It is morphologically distinct from typical cap-and-stem mushrooms, appearing as a compact, globular white mass covered in long, dangling spines that resemble a hedgehog or a lion's mane. Traditionally valued in East Asian medicine for treating memory impairment and gastrointestinal diseases, it has recently emerged as a significant subject for modern research into neurodegenerative disease prevention and functional food development.

The mushroom's therapeutic potential is primarily attributed to its rich profile of bioactive secondary metabolites, most notably polysaccharides (specifically *β*-glucans) and terpenoids known as hericenones and erinacines. These compounds are unique for their ability to cross the blood-brain barrier and stimulate the synthesis of nerve growth factor (NGF), which is essential for the growth, maintenance, and survival of neurons. Beyond its neuroprotective effects, *H. erinaceus* exhibits the following biological properties:

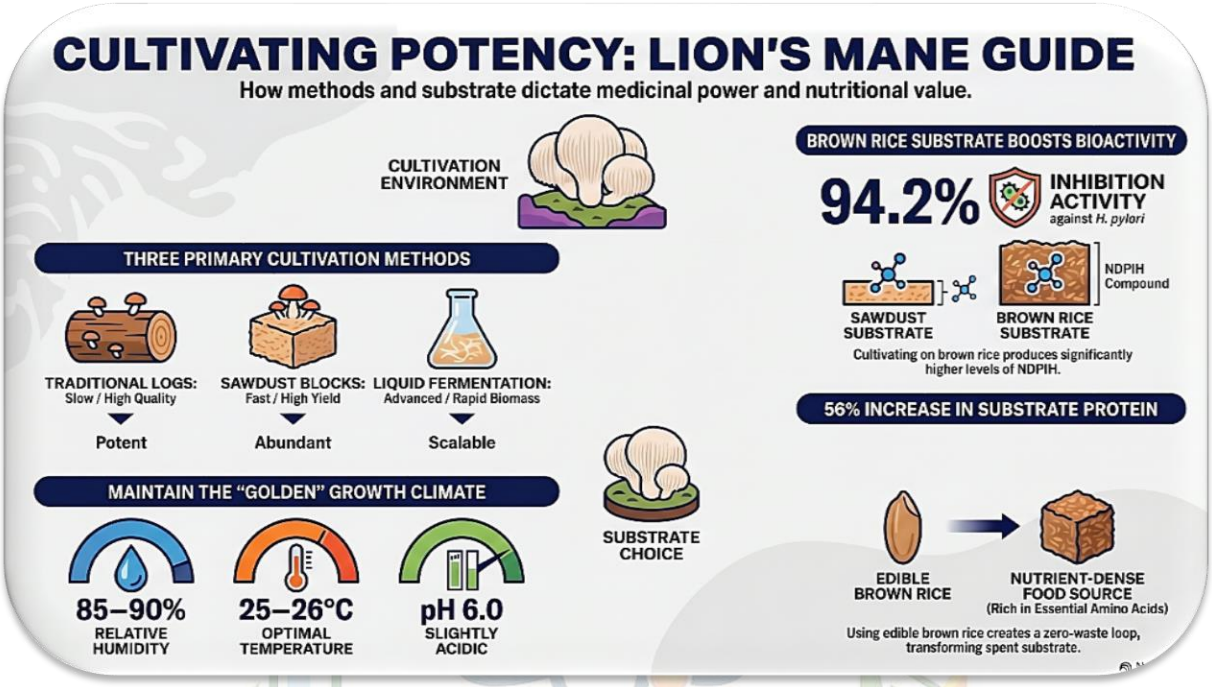
Antioxidant and Anti-inflammatory: It helps mitigate oxidative stress and chronic inflammation by scavenging reactive oxygen species and inhibiting pro-inflammatory pathways like *NF−κB*.

Antimicrobial Potential: It shows activity against various pathogens, including significant inhibitory effects on Helicobacter pylori, a major contributor to gastric ulcers.

Nutritional Enhancement: Recent innovations in sustainable cultivation have introduced the use of brown rice as a substrate. This method not only enhances the accumulation of bioactive metabolites like NDPIH (enhancing anti-*H. pylori* activity) but also improves the nutritional value of the spent substrate, which becomes rich in proteins and essential amino acids

The Cultivation and Comprehensive Benefits of Lion's Mane Mushroom

Hericium erinaceus, popularly known as **Lion's Mane**, is a unique toothed fungus native to the Northern Hemisphere, valued for centuries in East Asian medicine and gourmet cooking. Modern research highlights its significant potential in supporting **neurological, gastrointestinal, and metabolic health** through its rich profile of bioactive metabolites.



Cultivation Methodologies

The cultivation of Lion's Mane has evolved from traditional forest gathering to sophisticated industrial processes.

Traditional and Commercial Substrates: Naturally, the mushroom is **saprophytic**, growing on hardwoods like beech and maple. Commercial production typically uses **sawdust-based blocks**, wood logs, or stumps. Optimal growth requires a temperature of approximately **25-26°C**, high humidity (85–90%), and a pH near 6.0.

Sustainable Brown Rice Innovation: Recent research has developed an eco-friendly method using **brown rice** as an edible substrate. This method is highly sustainable because the **spent mushroom substrate (SMS)**—the leftover rice after harvest—becomes a nutrient-enriched functional food. After cultivation, the brown rice substrate shows a **56% increase in protein content** and a massive rise in essential free amino acids, such as phenylalanine and lysine.

Industrial Fermentation: Submerged culture fermentation is used to produce large volumes of mycelial biomass and bioactive compounds quickly. This method is preferred for pharmaceutical applications as it ensures a more uniform extract.

Comprehensive Health Benefits

1. Neuroprotection and Cognitive Support: Lion's Mane is most famous for its ability to stimulate the synthesis of **Nerve Growth Factor (NGF)**, a protein essential for the growth and survival of neurons.

a. Key Bioactive compounds: The fruiting bodies contain **hericenones**, while the mycelia are rich in **erinacines**. Both classes of compounds can cross the blood-brain barrier to promote **neurogenesis**.

b. Cognitive Enhancement: Clinical trials in older adults with mild cognitive impairment have shown significant improvements in cognitive performance after 16 weeks of supplementation.

c. Acute Effects: A study on healthy young adults found that a single 3g dose improved **psychomotor skills and manual dexterity** (measured by the pegboard test) within 90 minutes, though it did not produce immediate changes in global mood or general cognition.

2. Gastrointestinal Health: Traditionally used for gastric ulcers, the mushroom contains compounds that protect the mucosal lining and combat pathogens.

a. Anti-Helicobacter pylori Activity: Extracts have shown potent inhibitory effects against *H. pylori*, a major cause of ulcers and stomach cancer.

b. Substrate-Dependent Potency: Cultivation on **brown rice** significantly increases the concentration of **N-dephenylethyl isohericerin (NDPIH)**. NDPIH exhibits much stronger anti-*H. pylori* activity (94.2% inhibition) compared to hericene A, which is the dominant compound in traditional sawdust-grown mushrooms.

3. Antioxidant and Anti-inflammatory Properties: The mushroom acts as a powerful protector against oxidative stress and chronic inflammation.

a. Molecular Mechanisms: Bioactive compounds inhibit the **NF-κB signaling pathway**, reducing the production of pro-inflammatory cytokines like TNF-*α* and IL-6.

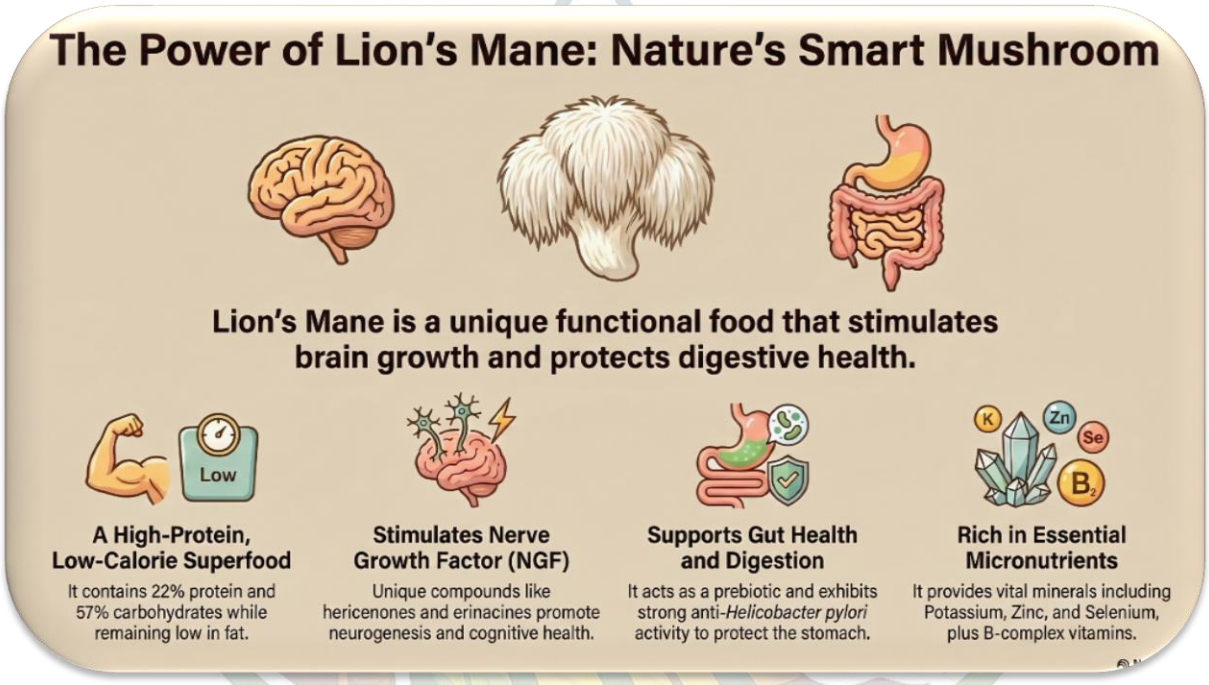
b. Antioxidant Defense: It upregulates endogenous enzymes like **superoxide dismutase (SOD)** and glutathione peroxidase, and it contains **ergothioneine**, a potent antioxidant that is actively transported into cells to mitigate damage.

4. Antimicrobial Potential: Lion's Mane demonstrates activity against a variety of pathogens, including **Gram-positive bacteria** like *Staphylococcus aureus* (including **MRSA**) and certain fungal strains like *Candida albicans*. These antimicrobial effects occur by disrupting microbial cell membranes and inhibiting the formation of **biofilms**.

5. Nutritional Profile: Nutritionally, the fruiting bodies are high in protein (approx. 22%) and dietary fibre, while remaining low in fat and calories. They are considered an excellent **meat substitute** for plant-based diets due to their high essential amino acid content and unique "umami" flavor.

Therapeutic and Nutritional Benefits

Hericium erinaceus, commonly known as **Lion's Mane**, offers a diverse range of therapeutic and nutritional benefits, acting as both a gourmet food and a potent medicinal agent. Its properties range from **neuroprotection and cognitive enhancement** to **gastrointestinal support and immune modulation**.



1. Nutritional Benefits: Lion's Mane is characterized by high nutrient density and a low-calorie profile, making it a valuable addition to balanced and plant-based diets.

Macronutrients: The fruiting bodies are a significant source of **protein (approximately 22%)** and **dietary fibre (8%)**, while containing very little fat (approx. 4%).

Micronutrients: It is rich in **B-complex vitamins** (B1, B2, B3, B5, B6), vitamin D precursors, and essential minerals such as **selenium, zinc, and potassium**.

Nutritional Enhancement *via* Brown Rice: Cultivating Lion's Mane on a **brown rice substrate** significantly enhances its nutritional value. This method results in a **56% increase in protein content** in the spent substrate and a dramatic rise in **free amino acids**. Essential amino acids like **phenylalanine** (a neurotransmitter precursor) and **lysine** increase by as much as 25-fold and 10-fold, respectively.

2. Therapeutic and Medicinal Properties: The mushroom's medicinal effects are primarily driven by unique secondary metabolites: **polysaccharides** (*β*-glucans) and **terpenoids** (**hericenones** in fruiting bodies and **erinacines** in mycelia).

Neuroprotection and Cognition

Lion's Mane is uniquely capable of stimulating **Nerve Growth Factor (NGF)** synthesis, which is critical for the survival and growth of neurons.

Neurodegenerative Disease: Its compounds, particularly erinacines, can cross the **blood-brain barrier** to promote neurogenesis and neuronal repair, showing potential in managing **Alzheimer's and Parkinson's** diseases.

Clinical Cognitive Effects: Studies in older adults with mild cognitive impairment have shown improved cognitive performance following 16 weeks of supplementation.

Acute Psychomotor Benefits: In healthy young adults, a single 3g dose has been shown to improve **psychomotor skills and manual dexterity** (manual speed and accuracy) within 90 minutes.

Gastrointestinal Health

Traditionally used to treat memory impairment and gastric diseases, modern research confirms its efficacy in supporting the gut.

Anti-*Helicobacter pylor*i Activity: Extracts demonstrate potent activity against *H. pylori*, a major contributor to gastric ulcers.

Compound Enhancement: Mushrooms grown on brown rice accumulate high levels of **NDPIH (*N*-dephenylethyl isohericerin)**, which exhibits significantly stronger anti-*H. pylori* activity (94.2% inhibition) compared to hericene A found in traditional sawdust-grown mushrooms.

Mucosal Protection: It supports intestinal barrier function, reducing inflammation and promoting tissue repair in conditions like gastritis and inflammatory bowel disease (IBD).

Antioxidant and Anti-inflammatory Action

Lion's Mane mitigates chronic inflammation and oxidative stress, which are underlying factors in many chronic diseases.

Molecular Pathways: Bioactive compounds inhibit the **NF-κB signaling pathway**, reducing the production of pro-inflammatory cytokines like **TNF-*α* and IL-6**.

Enzyme Induction: It induces endogenous antioxidant enzymes such as **superoxide dismutase (SOD)** and glutathione peroxidase to neutralize reactive oxygen species.

Ergothioneine: It contains ergothioneine, a potent antioxidant that is actively transported into cells to prevent damage to proteins and DNA.

Antimicrobial Potential

The mushroom exhibits broad-spectrum antimicrobial activity through the disruption of microbial cell membranes and metabolic pathways.

1. Pathogen Inhibition: It is effective against Gram-positive bacteria, including **Staphylococcus aureus (MRSA)** and *Bacillus subtilis*, as well as fungal pathogens like *Candida albicans*.

2. Antibiotic Synergetic Potential: Research suggests Lion's Mane may enhance the efficacy of existing antibiotics by increasing bacterial cell wall permeability.

Ecological Life Cycle and Survival

While often discussed as a supplement, the mushroom's life in the wild is characterised by long-term resilience:

1. Longevity: It is hypothesised that *H. erinaceus* can survive for up to **40 years**. Observations have shown it can fruit intermittently on the same dead tree for **20 years**.

2. Parasitic Nature: Though primarily saprophytic (feeding on dead wood), it can act as a facultative parasite on living trees, typically entering through wounds and causing a **white pocket rot** that eventually turns tissue spongy and forms cavities.

3. Mating and Reproduction: The species found in the U.S. uses a **bifactorially heterothallic** mating system. Interestingly, spore production peaks at **midday**, coinciding with rising temperatures and decreasing relative humidity.

Geographic Distribution and Host Specificity

The mushroom's presence varies significantly across different climates: California Oaks: In California, it specifically hosts various oak species, including Coast Live Oak, Canyon Live Oak, Interior Live Oak, California Black Oak, Blue Oak, and Valley Oak. European Conservation: Although native to Europe, it is red-listed in several European countries because it suffers from poor germination and establishment in that region. Regional Seasonality: In North America, fruiting times differ by region: October to February in the West, July to October in the Mountain states, and September to February in the East.

Pests and Competitors

Even a potent fungus faces biological threats in its environment; **Mite Pests:** A major pest in Chinese fungi culture is the mite *Brennandania lambi*, which reproduces on the mycelium. Management requires strict farm hygiene and heat treatments. Fungal Competition: H.erinaceus is a strong competitor against other wood colonisers. It can successfully maintain its territory on dead wood even when challenged by secondary colonisers like *Trametes versicolor* (Turkey Tail).

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Industrial and Regulatory Hurdles

The transition from a wild fungus to a commercial product faces specific barriers:

1. Lack of Western Breeding: While widespread in Asia, there is **little to no breeding** for higher yields or favourable traits in the U.S. or Europe, resulting in few commercially available industrial strains.

2. Regulatory Discrepancy: Within the UK and EU, **mycelial extracts** are currently prohibited in food products or supplements, while **fruiting body extracts** are permitted. This is a critical distinction for manufacturers because the mycelia contain different bioactive profiles (higher erinacines) than the fruiting bodies (Higher hericenones).

3. Extraction Sophistication: Moving beyond simple water/ethanol methods, researchers are exploring **supercritical fluid extraction** and **microwave-assisted extraction** to isolate specific terpenoids while preserving their bioactivity.

Conclusion

Hericium erinaceus (Lion's Mane) demonstrates strong potential as a functional food and therapeutic agent, with its efficacy significantly influenced by cultivation methods. Growing it on brown rice instead of sawdust alters its metabolic profile, increasing compounds like NDPIH that show enhanced activity against Helicobacter pylori. Additionally, this method transforms spent mushroom substrate into a nutrient-dense edible product, raising protein content by about 56% and enriching essential amino acids such as lysine and phenylalanine, making it useful for functional foods and meat alternatives. Although Lion's Mane is widely associated with cognitive benefits through nerve growth factor stimulation, short-term human studies show limited overall effects, with improvements mainly in psychomotor performance. Broader cognitive and mood benefits likely require long-term supplementation. While promising for neurodegenerative diseases, inflammation, and resistant infections, further large-scale clinical trials, standardized extraction methods, and research on bioavailability are essential.

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Aam Panna

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Dr. D. Rajani[1]
[1]Assistant Professor, College of Agriculture, PJTAU, Rajendranagar.

Aam (*Mango*) *Panna* (drink) is a seasonal drink prepared in most Punjabi homes during the hot summer season as a lemonade style drink. Raw green mangoes are preserved into a syrup-like concentrate together with sugar and then this mixed together with water and ice to prepare the refreshing cooler.

Raw mangoes in India make an appearance at vegetable and fruit vendors at the beginning of the summer season, often being the mangoes that fell off the trees too early. There are different varieties of raw mangoes and they vary in size, shape and flavour. At this stage, their flesh is white and very firm and are very sour to taste. They have various uses like being added to curries and *dals* as a souring agent (instead of say, tamarind), mango pickle, chutneys and this typical refreshing cooler. In fact, in India, we seldom cook savoury dishes with ripe mangoes, but these raw mangoes make a frequent appearance in the kitchen when they are in season.

If you cannot get your hands on raw green mangoes however, unripe mangoes that you would find in supermarkets can be used too, you just have to compensate for the missing acidity in these almost ripe mangoes with lime juice. Without the acidity, this drink would be only sweet and one dimensional.

Sugar in this recipe is used as a preservative for the mangoes and is a necessary addition when using raw green mangoes because they have no sweetness at all. The amount of sugar you will need to add depends on the type of mangoes you are using. When my mother makes *Aam Panna* with raw green mangoes, she uses 50% sugar to the weight of mangoes, so this would mean 500g sugar if you are using 1kg of mangoes. This might sound like a lot, however since this is a preserved concentrate, you only use a couple of tablespoons per glass of *Aam Panna*. This of it as you'd be making simple syrup or lemon cordial. However, we are using unripe mangoes commonly available in supermarkets here in Berlin and thus need less sugar in comparison. We recommend starting with less and then adding more depending on how sour your mangoes are.

A lot of recipes for *Aam Panna* add many different spices to the mix like cumin, black pepper and black salt. More common variants of the beverage are a sweet-salty version, however, my favourite version is sweet and simple with only mint and ginger as added flavourings. I find this to be much more refreshing when compared to salty variants that contain cumin. However, if you're looking to experiment, you can also add some roasted cumin seeds and black salt to the blend.

Method

1. Wash the mangoes well and then cook them in their skins as you would potatoes. You can boil them, steam them or cook them in a pressure cooker with a little water. They need to be completely soft and cooked through. Then set them aside to cool.

2. Once the mangoes are cool enough to handle, separate their pulp from their skins and seeds.

3. Blend together the mango pulp together with the ginger, mint leaves and sugar into the smooth consistency. Start with about 250g of sugar, taste and add more if needed. The amount of sugar depends on how sour your mangoes are. The concentrate should taste jam-like and should be on the sweeter side as it will later be diluted with water.

4. Depending on whether your mangoes are sour or not you may also have to add lime juice for added acidity. Our mangoes from the supermarket weren't sour at all, so we added 120ml of lime juice to the mix. The resulting concentrate should be sweet and tangy, if there isn't enough acid in the concentrate, the resulting drink would not be refreshing.

5. Tasting and adjusting the flavours is an important aspect of this recipe, and you should look out for a balance between the sweet and sour, in the concentrate, and keep in mind that it should be a little more sweet and sour to the tongue when you taste it as it will be diluted later-on.

6. Once the ingredients are all blended together in a thick smooth paste, transfer to a clean glass jar. This concentrate makes around 12 glasses of *Aam Panna* can be kept in the fridge for 1-2 weeks.

To prepare the *Aam Panna*, mix the concentrate with water and top with ice. This concentrate is thicker and jammier than a typical syrup and is best mixed in water with a whisk or a blender. You can also blend it together with crushed ice to make a margarita style drink.

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Aam Papad

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Dr. D. Rajani[1]
[1]Assistant Professor, College of Agriculture, Rajendranagar, PJTAU.

Aam Papad or **Mango Fruit Leather** is really healthy after school snack alternative and also is a wonderful homemade edible gift option for the festive season. We can make this using either the fresh mango extract or simply use the canned mango pulp which is available in almost all the Indian grocery shops. This **Mango Fruit Leather** is soft, chewy, and simply wonderful. It's easy to make, needs just one ingredient, far healthier and tastier than its processed counter parts, and feels like a burst of fruity sunshine.

Ingredients: 1½ - 2 cups Mango Puree, fresh or canned.

Cooking Time: 2-3 days when sun dried or 1½ - 2 hours in an oven.

Shelf Life: Up to a year when sundried and 1-2 months when cooked in an oven when stored in an air tight jar at room temperature.

Method

Sun dried method: Pour mango puree onto a large steel plate or tray or baking sheet. With a help of a spatula, spread purée on a steel plate/tray or baking sheet to 1/8 inch thickness. It may not extend all the way to edges, but make sure to spread as flat and as evenly as possible. Please do make sure that no part of tray or baking sheet is visible beneath purée.

a. Place the tray in an open space in the direct sunlight. Let it sundry for a day or two until the layer no longer sticks to your finger when pressed and is firmly set. Depending on the available sunlight, it may take 1-3 days for the layer to set.
b. You can add another cup of mango puree once the first layer has set firmly and let it sun dry for another 1-3 days and repeat the method 3-5 times to make thick layered Aam Papad.
c. Once set, run the knife through the set fruit leather to cut it into 1½ to 2 inch long stripes. Roll the stripes and store them in an air tight container. They are ready to eat immediately or can be stored for up to a year at room temperature.

Oven cooking method:

a. Preheat the oven to 110 ^{0}C and place the rack in the center of oven. Line a large rimmed baking tray or sheet with a parchment paper.
b. Pour mango puree onto a large steel plate or tray or baking sheet. With a help of a spatula, spread purée on a steel plate/tray or baking sheet to 1/8 inch thickness. It may not extend all the way to edges, but make sure to spread as flat and as evenly as possible. Please do make sure that no part of tray or baking sheet is visible beneath purée. If the puree is spread too thinly, it will cook quickly and harden to crisp in oven.
c. Let it cook for 1½ to 2 hours or until the fruit leather no longer feels sticky to touch and sets well. The baking time will vary from one oven to another based on the thickness of the puree, oven temperature and humidity. So keep a close watch after 1¼ hours and check every 15 minutes after that.
d. Remove the **Aam Papad or Mango Fruit Leather** from oven and remove it from the baking sheet along with the parchment paper. Let it cool completely before running the knife through the set fruit leather to cut it into 1½ to 2 inch long stripes. Roll the stripes and store them in an air tight container. They are ready to eat immediately or can be stored for 1-2 months at room temperature.

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CRISPR-Cas: Revolutionizing Plant Breeding

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Parshant Kumar Sharma[1], Mahendra Yadav[3], Naresh Lamba[3], Krishan Chaudhary[3]
[1]Department of Genetics and Plant Breeding, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi, India.
[3]Department of Dairy science and Food Technology, Banaras Hindu University, Varanasi, India.

Summary of Article

CRISPR-Cas technology has emerged as a powerful tool in modern plant breeding, enabling precise and efficient genome editing. Unlike traditional breeding methods, CRISPR allows targeted modification of specific genes responsible for important traits such as yield, disease resistance, and stress tolerance. This article highlights the role of CRISPR-Cas in accelerating crop improvement, reducing breeding time, and enhancing precision. It also discusses practical applications, advantages, and challenges associated with this technology. With increasing demand for food under changing climate conditions, CRISPR-based breeding offers a promising solution for developing climate-resilient and high-quality crop varieties. Overall, it represents a major advancement toward sustainable agriculture.

Introduction

Plant breeding has played a crucial role in increasing crop productivity; however, conventional breeding methods are time-consuming and less precise. With the advancement of molecular biology, new tools such as genome editing have revolutionized crop improvement. Among these, CRISPR-Cas technology has gained significant attention due to its simplicity, efficiency, and accuracy.

CRISPR (Clustered Regularly Interspaced Short Palindromic Repeats) along with Cas (CRISPR-associated protein) acts as a molecular scissor that can cut DNA at specific locations. This allows scientists to modify genes precisely without affecting other parts of the genome. As reported by **Jinek et. al., (2012)**, CRISPR-Cas9 has opened new possibilities for targeted genome editing in various organisms.

Role of CRISPR-Cas in Plant Breeding

CRISPR-Cas technology enables precise editing of genes responsible for important agronomic traits. It helps in developing improved crop varieties with desired characteristics in a shorter time compared to traditional breeding methods.

For example, CRISPR has been successfully used to develop disease-resistant rice and wheat varieties. According to **Zhang et. al., (2018)**, genome editing using CRISPR has significantly improved resistance against bacterial and fungal diseases in crops. Similarly, CRISPR-based approaches are being used to enhance drought tolerance and nutrient efficiency.

Applications in Crop Improvement

CRISPR technology has wide applications in plant breeding. It is used for improving yield, enhancing nutritional quality, and developing resistance against biotic and abiotic stresses. For instance, editing genes related to drought tolerance helps crops survive under water-limited conditions.

Moreover, CRISPR is also used in biofortification to improve the nutritional value of crops. As reported by **Chen et. al., (2019)**, genome editing has been applied to increase micronutrient content in staple crops, addressing malnutrition issues.

Table 1. Comparison of Conventional Breeding and CRISPR-Based Breeding:

Parameter	Conventional Breeding	CRISPR-Based Breeding
Time required	Long (years)	Short (few years)
Precision	Low	High
Gene targeting	Random	Specific
Efficiency	Moderate	High
Trait improvement	Limited	Highly efficient

Advantages of CRISPR-Cas Technology

CRISPR-Cas offers several advantages over traditional breeding methods. It is highly precise, cost-effective, and faster. It allows modification of specific genes without introducing foreign DNA, making it more acceptable compared to transgenic approaches. Additionally, it can be used across a wide range of crops.

Challenges and Limitations

Despite its advantages, CRISPR technology faces certain challenges such as off-target effects, regulatory issues, and public acceptance. According to **Bortesi and Fischer, (2015)**, proper validation and regulation are required to ensure safe application of genome editing technologies.

Personal Opinion

CRISPR-Cas technology has the potential to transform plant breeding by making it faster and more precise. However, its success depends on proper regulation, public awareness, and accessibility to researchers and farmers.

Summary/Conclusion

CRISPR-Cas technology represents a major breakthrough in plant breeding by enabling precise and efficient gene editing. It accelerates crop improvement, enhances stress tolerance, and improves nutritional quality. Although challenges such as regulation and public acceptance exist, continuous advancements are making this technology more practical. In the future, CRISPR-based breeding will play a key role in ensuring sustainable agriculture and global food security.

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Speed Breeding: A Key Tool for Climate-Resilient Agriculture

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Anil H M[1], Naga Jyothi Naganaboina[2], Jyoti I Tondi[3], Preethi L R[4], Moulya G[5]

[1]Ph.D. Scholar, Division of Genetics, Indian Agricultural Research Institute, New Delhi.
[2]Ph.D. Scholar, Division of Plant Pathology, Indian Agricultural Research Institute, New Delhi.
[3]Ph.D. Scholar, Division of Genetics and Plant Breeding, University of Agricultural Sciences, Dharwad.
[4]Ph.D. Scholar, Division of Genetics and Plant Breeding, University of Agricultural Sciences, Dharwad.
[5]Ph.D. Scholar, Division of Genetics and Plant Breeding, University of Agricultural Sciences, Dharwad.

Introduction

Global agriculture is increasingly challenged by climate change, population growth, and resource limitations. Developing climate-resilient crop varieties within shorter timeframes has become a priority. Conventional breeding methods are often time-consuming, requiring several years to develop improved cultivars. In this context, speed breeding has emerged as an innovative approach that accelerates plant growth cycles, enabling multiple generations per year under controlled environmental conditions (Watson et al., 2018). Speed breeding integrates extended photoperiods, optimized temperature regimes, and controlled environments to significantly reduce generation time. This technique is particularly valuable for rapidly advancing breeding populations and facilitating genetic studies aimed at improving crop resilience to environmental stresses.

Concept of Speed Breeding

Speed breeding refers to the manipulation of environmental conditions such as light intensity, photoperiod, temperature, and humidity to accelerate plant development and reproduction. By extending the photoperiod to up to 22 hours of light per day, plants can complete their life cycle much faster than under natural conditions. The concept is based on the principle that plant growth and flowering are strongly influenced by environmental cues. By optimizing these conditions, breeders can achieve up to 4–6 generations per year in crops like wheat, barley, chickpea, and canola (Watson et al., 2018).

Principles and Techniques

Speed breeding is founded on the strategic manipulation of environmental conditions to accelerate plant growth, flowering, and seed production. These principles are carefully optimized to shorten the life cycle of crops while maintaining plant health and reproductive success.

1. Extended Photoperiod: One of the core principles of speed breeding is the use of extended photoperiods, often up to 20–22 hours of light per day. Prolonged light exposure enhances photosynthetic activity, leading to faster biomass accumulation and earlier transition from vegetative to reproductive stages. This is particularly effective in long-day crops such as wheat and barley, where flowering is strongly influenced by light duration. The use of LED lighting systems ensures uniform light intensity and energy efficiency, further improving growth rates.

2. Controlled Temperature: Temperature regulation is critical for optimizing plant metabolism and developmental processes. Maintaining optimal day and night temperatures accelerates physiological activities such as cell division, enzyme function, and flowering. Controlled temperature regimes also help avoid stress conditions that could otherwise delay growth or reduce seed viability. Precise temperature management ensures synchronization of plant development across generations.

3. Early Harvesting and Seed Handling: Speed breeding involves harvesting seeds at physiological maturity rather than waiting for complete drying on the plant. These seeds are then subjected to rapid drying and, if necessary, treatments such as cold stratification or dormancy breaking. This practice significantly reduces the interval between successive generations, enabling rapid cycling without compromising seed quality or germination potential.

4. Use of Growth Chambers and Greenhouses: Controlled environments such as growth chambers and glasshouses provide stable and reproducible conditions for implementing speed breeding protocols. These facilities allow precise control over light, temperature, humidity, and carbon dioxide levels, ensuring consistent plant growth throughout the year. Additionally, automation and environmental monitoring systems enhance efficiency and scalability.

5. Integration with Molecular Tools: Speed breeding is increasingly combined with molecular breeding approaches such as marker-assisted selection, genomic selection, and genome editing. This integration enables simultaneous advancement of generations and selection of desirable traits at the molecular level. By combining rapid generation turnover with precise genetic selection, breeders can significantly accelerate crop improvement programs.

Role in Climate-Resilient Agriculture

Speed breeding plays a pivotal role in addressing the challenges posed by climate change by enabling the rapid development of crop varieties that are resilient to environmental stresses. Its ability to shorten breeding cycles allows faster incorporation of adaptive traits into elite cultivars.

1. Accelerated Development of Stress-Tolerant Varieties: Speed breeding facilitates the rapid introgression of genes associated with tolerance to drought, heat, salinity, and other stresses. By advancing multiple generations per year, breeders can quickly combine desirable traits and evaluate their performance under controlled and field conditions. This accelerates the development of climate-resilient cultivars capable of maintaining productivity under adverse conditions.

2. Faster Screening of Germplasm: Large and diverse germplasm collections can be evaluated efficiently using speed breeding protocols. Rapid cycling allows breeders to screen multiple generations within a short period, enabling the identification of superior genotypes with enhanced resilience. This is particularly important for exploiting genetic diversity and identifying novel sources of stress tolerance.

3. Rapid Response to Climate Change: Climate change is dynamic and unpredictable, requiring flexible and responsive breeding strategies. Speed breeding allows researchers to quickly test and adapt breeding materials to emerging environmental conditions. This responsiveness is crucial for developing crop varieties that can cope with new stress scenarios, pest outbreaks, and shifting agro-climatic zones.

4. Enhancement of Genetic Gain: By reducing the duration of each breeding cycle, speed breeding increases the rate of genetic gain per unit time. This means that improvements in yield, stress tolerance, and quality can be achieved more rapidly compared to conventional breeding methods. Enhanced genetic gain is essential for meeting the growing demand for food under limited resources and changing climatic conditions.

Integration with Modern Breeding Approaches

The true potential of speed breeding is realized when it is integrated with advanced breeding technologies, creating a synergistic approach that combines speed with precision and efficiency. Genomic selection enables the prediction of breeding values using genome-wide markers, allowing early and accurate selection of superior genotypes. When combined with speed breeding, it significantly reduces the time required for selection and advancement of breeding lines. CRISPR-based genome editing provides a powerful tool for precise modification of target genes associated with important traits. Integration with speed breeding allows rapid fixation and evaluation of edited traits across generations. High-throughput phenotyping technologies complement speed breeding by enabling rapid and non-destructive assessment of plant traits. These tools provide accurate phenotypic data that can be integrated with genomic information for improved selection decisions. Artificial intelligence and machine learning further enhance this integration by analyzing large datasets, identifying patterns, and predicting trait performance under different environmental conditions. These technologies support data-driven breeding strategies and improve decision-making efficiency (Hickey et al., 2019).

Applications in Major Crops

Speed breeding has demonstrated remarkable success across a wide range of crop species, highlighting its adaptability and effectiveness in modern breeding programs. In cereal crops such as wheat and barley, speed breeding has enabled the rapid development of varieties with improved resistance to diseases like rust and powdery mildew, along with enhanced tolerance to heat and drought stress. The shortened generation time allows breeders to combine multiple desirable traits within a few years, significantly accelerating varietal release.

1. In rice, speed breeding has been utilized to develop high-yielding and stress-tolerant lines, particularly for conditions such as salinity, submergence, and drought. Controlled environments facilitate precise evaluation of stress responses, enabling efficient selection of superior genotypes.

2. Among legumes, crops such as chickpea and pea have benefited from rapid generation advancement, leading to the development of drought-tolerant and early-maturing varieties. This is particularly important in rainfed regions where climate variability affects crop productivity.

3. In oilseed crops like canola, speed breeding has enhanced breeding efficiency by enabling faster incorporation of traits related to oil quality, disease resistance, and abiotic stress tolerance. Overall, these applications demonstrate the versatility and scalability of speed breeding across diverse crop groups and agro-ecological conditions (Ghosh et al., 2018).

Advantages

Speed breeding offers several significant advantages that make it a transformative tool in crop improvement. One of the primary benefits is the substantial reduction in breeding cycle duration, allowing multiple generations to be completed within a single year. This accelerates the development of improved cultivars and reduces the time required for varietal release. Another major advantage is the increase in genetic gain per unit time. By shortening generation intervals,

breeders can achieve faster accumulation of desirable traits such as yield, stress tolerance, and quality. Speed breeding also facilitates rapid introgression of target genes into elite backgrounds, improving breeding precision and efficiency. Furthermore, the approach supports seamless integration with modern technologies such as genomic selection, molecular markers, and genome editing. This integration enhances selection accuracy and enables data-driven breeding decisions. Additionally, controlled environments reduce environmental variability, leading to more consistent and reliable phenotypic evaluation.

Challenges and Limitations

1. Despite its numerous advantages, speed breeding faces several challenges that limit its widespread adoption. One of the major constraints is the high initial cost associated with establishing controlled environment facilities, including growth chambers, lighting systems, and climate control equipment. This can be a significant barrier, particularly for resource-limited institutions.

2. The requirement for precise environmental control also demands technical expertise and continuous monitoring, which increases operational complexity. Any deviation from optimal conditions may adversely affect plant growth and seed quality.

3. Another limitation is its restricted applicability to certain crop types. While speed breeding is highly effective in annual crops, its use in perennial crops and long-duration species remains limited due to inherent biological constraints.

4. Additionally, the accelerated growth conditions may not fully replicate natural field environments, potentially affecting the expression of some traits. Therefore, field validation remains essential to confirm the performance of developed lines.

5. Addressing these challenges through technological advancements, cost reduction, and capacity building will be crucial for the broader adoption of speed breeding in global agriculture.

Future Perspectives

The future of speed breeding lies in its integration with digital agriculture, automation, and omics technologies. Advances in LED lighting, climate-controlled systems, and artificial intelligence are expected to further enhance its efficiency and scalability. Speed breeding is likely to become a cornerstone of next-generation breeding programs aimed at ensuring food security and sustainability under changing climatic conditions.

Conclusion

Speed breeding represents a transformative approach in modern agriculture by significantly reducing the time required for crop improvement. Its ability to accelerate breeding cycles and enhance genetic gain makes it a key tool for developing climate-resilient crop varieties. When integrated with advanced molecular and computational tools, speed breeding has the potential to revolutionize plant breeding and contribute to sustainable agricultural systems.

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Decade wise Productivity of Major Crops in Maharashtra

Article ID: 73604

Sangita J. Kadlag[1]

[1]Assistant Professor of Agricultural Economics, MVP's K.D.S.P College of Agriculture, Chachadgaon , Nashik-Peth Highway Nashik.

Introduction

Agriculture in Maharashtra is a vital sector engaging over half the population, characterized by diverse agro-climatic zones and a shift from traditional subsistence to commercial, high-value farming. The state is a top producer of cotton, soybeans, sugarcane, and horticultural crops (grapes, mangoes, oranges), with recent growth driven by technological adoption despite regional rainfall dependencies and productivity challenges.

Irrigation inadequacy, water scarcity, erratic monsoon patterns, and low-fertility soils are the primary factors impacting crop productivity in Maharashtra, leading to significant yield fluctuations across the state. With over 80% of agriculture being rainfed and less than 20% of the area under irrigation, crops are highly sensitive to climatic vagaries, particularly in Marathwada and Vidarbha.

The Key Factors Affecting Crop Productivity in Maharashtra

1. Environmental and Climatic Factors (Abiotic):

a. Water Scarcity and Rainfall Dependence
b. Climate Change & Temperature Fluctuations
c. Soil Degradation and Fertility

2. Technological and Agricultural Factors:

a. Low Seed Quality & Variety Selection
b. Under-mechanization and Poor Irrigation Infrastructure
c. Pest and Disease Management

3. Socio-Economic Factors:

a. Small and Fragmented Landholdings
b. High Input Costs and Debt
c. Inadequate Extension Services

4. Regional Crop Specifics:

a. Sugarcane (Western Maharashtra): High water consumption leads to pressure on groundwater, making it vulnerable during drought years despite irrigation.

b. Cotton and Soybean (Vidarbha/Marathwada): High susceptibility to erratic rainfall and boll-forming issues due to pests.

c. Rabi Jowar/Gram (Drought-prone areas): Limited by available soil moisture and decreasing rainfall, leading to low productivity in areas like Solapur.

d. Rice (Konkan): High rainfall and waterlogged, low-fertility lateritic soils require specific nutrient management.

Table no -1 Details of Decade wise productivity and highest productivity of different crops in Maharashtra (Productivity Kg /ha And Sugarcane productivity tonnes/ ha):

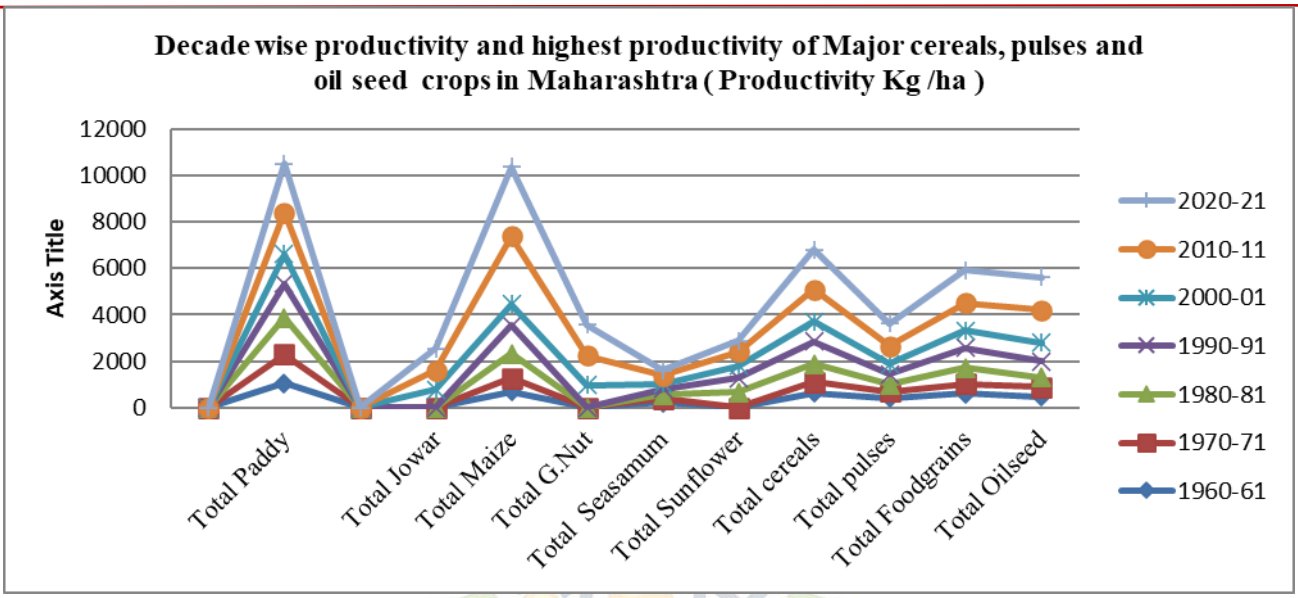
Sr no	Crop	1960-61	1970-71	1980-81	1990-91	2000-01	2010-11	2020-21	Highest productivity (Kg/ha)	Highest productivity year
1	Kharif Paddy	1054	1229	1587	1467	1264	1766	2056	2333	2016-17
2	Summer Paddy	--	--	--	--	2010	2228	3001	3001	2020-21
3	Wheat	442	542	834	1049	1256	1761	1839	1912	2022-23
4	Kharif Jowar	864	350	956	1379	1256	1325	1007	1818	1996-97
5	Rabi Jowar	541	212	448	598	499	689	930	1043	2022-23
6	Bajra	299	404	454	575	604	1086	1317	1317	2020-21
7	Ragi	741	855	945	1025	830	978	1151	1415	2022-23
8	Kharif Maize	697	559	1072	1203	832	3024	3241	3541	2013-14
9	Rabi Maize	--	--	--	--	1198	2630	2616	3503	2021-22
10	Summer Maize	--	--	--	--	1609	1405	1547	2154	2016-17
11	Tur	883	432	495	417	602	750	1082	1455	2016-17

12	Green Gram	--	--	--	--	341	672	517	672	2010-11
13	Black gram	--	--	--	--	357	682	636	685	2011-12
14	Gram	334	281	336	532	519	904	1074	1145	2021-22
15	Kharif G.Nut	739	649	610	923	893	1255	1197	1255	2010-11
16	Summer G.Nut	--	--	1529	1643	1263	1395	1647	1687	2019-20
17	Kharif Seasamum	219	165	244	297	215	360	239	392	1992-93
18	Rabi Seasamum	210 (1968-69)	113	68	121	201	285	308	680	2021-22
19	Summer Seasamum	--	--	--	--	--	--	181	245	2019-20
20	Niger	210(1968-69)	169	185	235	219	312	225	387	2022-23
21	Kharif Sunflower	--	--	654	482	493	513	454	654	1980-81
22	Rabi Sunflower	--	--	750	658	536	646	524	1014	2021-22
23	Summer Sunflower	--	--	--	770	584	984	484	1523	2018-19
24	Soybean	--	--	330(1984-85)	947	1109	1581	1460	1581	2010-11
25	Linseed	227	158	137	208	233	264	321	546	1999-00
	Safflower	199(1968-69)	252	363	408	412	544	569	767	2022-23
26	Sugarcane	67	87	92	86	83	89	98	107	1998-99
27	Cotton	114	30	82	117	100	322	378	434	2016-17
28	Tobacco	--	--	--	--	--	--	2015	2637	2022-23

(Source: Kharif niyojan)

Table no -2 Details of Decade wise productivity and highest productivity of Major cereals, pulses and oil seed crops in Maharashtra (Productivity Kg /ha)

Sr no	Crop	1960-61	1970-71	1980-81	1990-91	2000-01	2010-11	2020-21	Highest productivity (Kg/ha)	Highest productivity year
	Total Paddy	1054	1229	1587	1467	1277	1775	2109	1249	2022-23
	Total Jowar	--	--	--	--	761	850	942	1029.3	2022-23
	Total Maize	697	559	1072	1203	921	2923	2982	3300	2013-14
	Total G.Nut	--	--	--	--	958	1290	1318	1318	2020-21
	Total Seasamum	219	155	170	262	221	356	227	356	2010-11
	Total Sunflower	--	--	669	609	520	613	468	686	2007-08
	Total cereals	637	459	788	964	865	1371	1724	1945	2022-23
	Total pulses	421	264	304	442	460	767	967	1052	2016-17
	Total Foodgrains	598	420	692	846	757	1183	1426	1474	2022-23
	Total Oilseed	473	410	426	666	820	1394	1422	1422	2020-21



Decade wise analysis of agricultural productivity in Maharashtra reveals a consistent, long-term **upward trend in overall food grain and commercial crop production**, driven by a gradual shift from low-value food grains to high-value commercial crops, improved irrigation, and the adoption of modern technology. While productivity improved, the growth has often been characterized by volatility, particularly in oilseeds and pulses.

In conclusion, Maharashtra's agricultural sector has transitioned from subsistence to commercial farming over the past few decades, resulting in higher overall production and productivity, though with significant regional and crop-wise disparities in growth.

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Use of *Dimeria ornithopoda* as Green Fodder in Goat

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Dharmendra Kumar[1], Kushalendra Kumar[1], Sanjay Kumar[1], Pankaj Kumar Singh[1], Sankhnath Koley[1], Vishwajeet Kumar[1], Durgesh Nandini[1]

[1]Department of Animal nutrition, Bihar veterinary College, Patna, Bihar Animal Sciences University, Patna Bihar.

India's goat population is 148.88 million that grew by ~10% between 2012 and 2019 while Bihar has total goat population 12.82 million grew by ~5.49% between 2012 and 2019 underlining its importance as a source of livelihood, nutrition, and income, especially for economically disadvantaged rural families. Goat account for 27.8% of India's total livestock in 2019 contributes meaningfully to meat and milk sectors with a 4.63% increase in overall livestock numbers. The Black Bengal goat is a native breed of Eastern India renowned for its superior meat quality, high fecundity, and adaptability to local agro-climatic conditions, forms a substantial part of the small ruminant population in the region. The productivity and health of goats are directly influenced by the quality and quantity of available feed, which remains a challenge due to seasonal fluctuations and limited availability of conventional fodder

Addressing this feed gap with non-conventional but nutritionally promising alternatives is essential for sustainable goat farming. Also, scarcity feed during the lean seasons poses a significant challenge for goat farming across Bihar, severely limiting the growth and productivity of the animals. So to counter this deficit, non-conventional fodder like *Dimeria ornithopoda* could be a better option. *Dimeria ornithopoda* is naturally grown grass on unused land. *Dimeria ornithopoda* has a great opportunity for exploration as a non-traditional fodder due to its wide availability in barren land. *Dimeria ornithopoda* is commonly known as Khar, Madua, is a perennial grass species belonging to the family Gramineae or Poaceae monocotyledonous flowering plants, with flat, hollow stem found as grasses on bund and unutilized land known for its resilience to harsh conditions. The flowering season generally peaks in November to December. Leaves are medium, narrow, length of 25-30 cm with width- 0.5-0.7 cm and hairy parallel venation, surrounding internodes incompletely. Flower is inflorescences, soft, feather-like spikes, purple to brown in color.

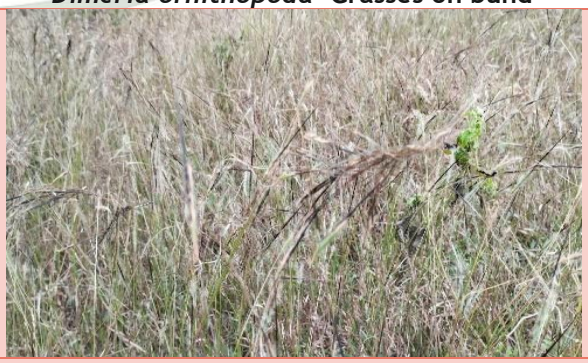


***Dimeria ornithopoda* in plain field**



***Dimeria ornithopoda* Grasses on bund**





Grasses on hills

Common name: Khar, Madua

Family: Graminae or Poaceae

Perennial, Monocotyledonous flowering plants, Feather grass, Height :2-3 ft

Stem: Flat, hollow, Internodes- 3-4 cm, hairy

Leaves: medium, Narrow, length; 25-30 cm, width- 0.5-0.7 cm) and hairy parallel venation. surrounding internodes incompletely.

Flower: Inflorescences: Soft, **feather-like spikes,** purple to brown in color

The flowering season generally peaks in late **November to December**.

Growth Habit: Forms dense clumps, often creating beautiful swaths of greenery.



Tillars



Seed of *Dimeria Ornithopoda*





Seed of *Dimeria ornithopoda*





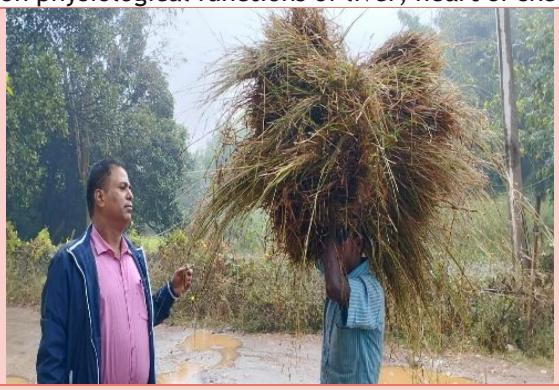
Animals rearing in this area

Fibrous roots forming a sturdy network underground, stabilizing the soil. Reproduction primarily occurs through seeds, which are dispersed by the wind. Found in sandy soil, Barren land and only naturally growing not cultivated.

The geographical area of the district is 305621 hectare out of this 84,5,68 ha land having this grasses with average productivity of 1325 kg / ha. Height of grass was 2.3ft. and having 12-15 tillers. Thickness and biomass is more than double on bund of paddy fieldThe grasses with average productivity of 1520kg / ha. Height of grass was 2.1ft. and having 12-15 tillers. Thickness and biomass is more than double on bund of paddy field. In December month grasses were highly mature in condition. Seeds were also matured. Grasses were available in protected area and forest area which was not approachable to animal. After December they not grow but regenerate in next rainy season by fallen seed. This grass is relatively drought-tolerant, making it suitable for rainfed areas. Goats find *Dimeria ornithopoda* highly palatable, reducing wastage and increasing intake. The grass is a good source of protein, energy, and fibre, supporting goat growth and productivity.

The palatability (DMI g/day) of *Dimeria ornithopoda* were 98.0 ± 0.02 for growing black Bengal goats, which showed that *Dimeria ornithopoda* had lower palatability. The chemical composition (%) of *Dimeria ornithopoda* in 120- days and 75 days were 30.54, 20.2; 4.82, 5.43; 39.8,27.2; 1.28, 2.3; 5.8,5.3; 0.19, 0.12; 0.08, 0.05; 2.2, 2.1; 69.3,67.06; 49.2, 38.2 for DM, CP, CF, EE, TA, Ca, P, AIA, ADF and NDF, respectively. The trace mineral composition (ppm) were Cu 21.23, Zn 21.84, Mn 96.42, Fe 239.42, respectively.

Non Descript breed of cow and goat graze in pasture land from July to December. After this they provide only straw in night and morning. Peak production of cow was 1.25- 2.25 kg milk /day with lactation length 6-8 months. Some farmers fed 10-15 kg grass to their cow after chaffing. It indicates that the feeding of *Dimeria ornithopoda* fodder had no adverse effect on physiological functions of liver, heart or skeletal muscles. The serum Ca and P values were statistically similar.



Collection of grasses by farmers



Chaffing of *Dimeria Ornithopoda*

Dimeria ornithopoda contains anti-nutritional factors like oxalates, which can affect mineral availability. The grass's high fibre content may affect digestibility, requiring careful feeding management. Include *Dimeria ornithopoda* at 30-50% of the total diet, depending on the goat's nutritional requirements.

Supplementation: Provide concentrate supplements to balance the diet and ensure adequate nutrient intake.

Feeding Management: Offer fresh grass daily, and ensure access to clean water and mineral blocks

Conclusion

Dimeria ornithopoda can be a valuable green fodder source for goats, offering nutritional benefits and high yields. However, careful feeding management and mineral supplementation are essential to ensure optimal goat health and productivity.

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From Petals to Profits: Women Empowerment through Value Addition in Flower Crops

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E. Anbazhagan[1], Dr. G. Sathish[2], Dr. M. Kabilan[3]

[1]M. Sc., Research Scholar, Department of Floriculture & Landscape Architecture, Tamil Nadu Agricultural University, Coimbatore – 641003.

[2]Associate Professor, Dept of Fruit Science, HC&RI, Periyakulam, Theni, TNAU, Tamil Nadu.

[3]Division of Agricultural Chemistry, Regional Coffee Station, Thandigudi, Dindigul, Tamil Nadu.

Introduction

India is a leading producer of ornamental flowers, with floriculture emerging as a key component of horticultural diversification due to its strong economic and employment potential. The sector covers about 3.4 lakh hectares, producing over 2.7 million tonnes of loose flowers and 0.8 million tonnes of cut flowers annually. Major crops like rose, jasmine, marigold, chrysanthemum, and tuberose are widely grown for cultural and decorative uses. However, 20–30% post-harvest losses occur due to perishability and poor handling.

Value addition offers an effective solution by converting surplus flowers into products such as essential oils, rose water, gulkand, natural dyes, cosmetics, and garlands. These products increase shelf life, enhance market value, and create opportunities in multiple industries. With low investment and simple techniques, such activities are ideal for women self-help groups, promoting employment, income generation, and sustainable rural livelihoods.

Why Value Addition is Essential in Flower Crops?

Value addition plays a crucial role in transforming traditional floriculture into a profitable enterprise. Fresh flowers are highly perishable and often face market price fluctuations, resulting in economic losses for growers. By converting flowers into value-added products, farmers especially women entrepreneurs can significantly increase income and reduce post-harvest losses.

Reduces Post-Harvest Losses: Nearly 25 - 40% of flowers are lost after harvest due to poor storage, transportation, and market gluts. Processing surplus flowers into various products helps minimize wastage and ensures better utilization of floral resources.

Extends Shelf Life: Processing flowers into products like rose water, potpourri, dried petals, and floral powders increases shelf life and allows storage and marketing for longer periods.

Increases Income: Value-added products such as essential oils, gulkand, herbal teas, and floral extracts can generate 2-5 times higher returns compared to selling fresh flowers in local markets.

Creates Women-Led Enterprises: Activities such as garland making, floral craft production, drying flowers, and preparing herbal products require low investment and simple technology, making them ideal livelihood options for rural women and Self-Help Groups (SHGs).

Promotes Rural Entrepreneurship: Value addition encourages the establishment of small-scale cottage industries, supporting rural employment and strengthening local economies.

Strengthens the Floriculture Value Chain: Processing, packaging, branding, and marketing of floral products create additional economic activities, increasing profitability and long-term sustainability of the floriculture sector.

Value Addition Opportunities in Flower Crops with Government Support Schemes

Flower Crop	New Value-Added Products	Business Opportunity	Supporting Government Scheme
Rosa damascena	Rose syrup, rose jam, rose face mist, floral ice cubes, edible rose powder	Food products, cosmetics, wellness products	Mission for Integrated Development of Horticulture, PM Formalisation of Micro Food Processing Enterprises Scheme
Jasminum sambac	Jasmine perfume, incense sticks, scented candles, jasmine tea	Fragrance industry, spiritual products	Pradhan Mantri Mudra Yojana
Polianthes tuberosa	Essential oil, floral perfume, aroma diffuser oil, scented sachets	Perfume and aromatherapy industry	Agriculture Infrastructure Fund

Tagetes erecta	Natural dye, lutein extract, organic colour powder, temple waste incense sticks	Food colour, poultry feed, eco-products	Mission for Integrated Development of Horticulture
Chrysanthemum indicum	Chrysanthemum herbal tea, dried floral decorations, floral powder	Herbal beverage and craft industry	PM Formalisation of Micro Food Processing Enterprises Scheme
Hibiscus rosa-sinensis	Hibiscus shampoo, herbal tea, hair oil, natural dye powder	Herbal cosmetics and health products	National Rural Livelihood Mission
Calendula officinalis	Skin balm, herbal soap, medicinal ointments, dried petals	Pharmaceutical and cosmetic industries	Startup India

Value Addition in Rose

1. Essential Oil: Essential oil (attar or rose otto) is an important value-added product extracted from rose petals and widely used in perfume, cosmetic, and medicinal industries.

In India, rose oil is mainly extracted from *Rosa damascene*, *Rosa bourboniana, Rosa centifolia, Rosa alba, and Rosa gallica*. Among these, *Rosa damascena* is the most important commercial species with the highest oil yield (about 0.057%).

Major chemical constituents of rose oil include geraniol, citronellol, nerol, linalool, and phenyl ethyl alcohol, which provide the characteristic fragrance and therapeutic properties.



2. Gulkand: Gulkand is prepared by mixing equal proportion (1:1) of petals and white sugar. Flower petals of *Rosa damascena, R.gallica* and *R. chinensis* are suitable for making gulkand.

Gulkand is rich in antioxidants. It is used as cooling tonic and laxative and to cure heart related problems. It is widely used in pan, shakes, sweets, ice creams, confectionery, etc.



3. Rose water: Rose water can be prepared by boiling of rose petals in water. The suitable species are *Rosa damascena, R.borboniana, R.centifolia, R.alba and R.gallica*. Rose water has antiseptic and cooling properties. It is used in eye lotions, eye drops, skin tonics etc.





4. Rose tea: Rose petals and fruits are used for preparing tea. Petals contain tannins. Hips of dog rose (*Rosa canina*) and rugosa rose (*Rosa rugosa*) are very rich in vitamin C.

Hips contain vitamin C (150mg/100g fresh weight), minerals (Calcium, potassium and phosphorus), anti-inflammatory, antioxidant and diuretic properties.





5. Gulroghan: Rose hair oil is prepared by enfleurging the rose petals with sesame seeds. It is also used in aromatherapy.





Value Addition in Jasmine

1. Jasmine tea: Jasmine tea is a popular aromatic beverage prepared by blending tea leaves with fresh jasmine flowers. It is valued for its pleasant fragrance and refreshing taste. *Jasminum sambac* and *Jasminum grandiflorum* are commonly used for preparing jasmine tea.

Fresh jasmine blossoms are mixed with green or black tea leaves so that the tea absorbs the natural floral aroma during the scenting process. Jasmine tea is known for its **antioxidant, relaxing, and digestive properties**, making it popular in health and wellness beverages.

Production of jasmine tea offers **small-scale business opportunities for women entrepreneurs and Self-Help Groups (SHG's)** in floriculture value addition.





2. Wedding Garlands: Wedding garlands are one of the most traditional and commercially important value-added products prepared from fresh flowers. They play a significant role in marriage ceremonies and cultural rituals. Garland making is a **labour-intensive activity that requires simple skills and low investment**, making it an ideal livelihood opportunity for rural women and Self-Help Groups (SHGs).

This enterprise provides **regular income through local flower markets, temples, and wedding events**, contributing to women empowerment in the floriculture sector.



3. Tinting: Tinting of flowers is a low-cost value addition technique where white flowers are coloured using dye solutions absorbed through the stem. Common flowers include carnation, tuberose, rose, and chrysanthemum. It enhances visual appeal and market value for decorative uses. This simple method is ideal for women and SHGs, helping reduce wastage and generate additional income.



Value Addition in Marigold

1. Textile Industry Marigold Natural Dye: *Tagetes erecta* flowers are used as natural dyes in the textile industry. Marigold pigments produce bright yellow to orange shades, making them suitable for dyeing cotton, silk, and wool fabrics.These dyes are biodegradable, non-toxic, and environmentally friendly, supporting sustainable textile production.

Preparation of natural dyes from marigold flowers can provide small-scale business opportunities for rural women and Self-Help Groups (SHGs) in value-added floriculture enterprises.



2. Poultry Feed Marigold: Powder from dried flowers of *Tagetes erecta* is rich in lutein pigment. It is used as a natural poultry feed additive to enhance the yellow colour of egg yolk and improve egg quality.
Marigold-based feed additives provide a natural alternative to synthetic pigments in poultry production.



3. Food Industry: Marigold serves as a natural food colorant, providing vibrant yellow and orange hues to cheeses, butters, and other food products.

Its extracts, rich in carotenoids like lutein and zeaxanthin, are used to enhance the visual appeal of foods and beverages. The petals are also used in salads, teas, and as a culinary garnish due to their mild, tangy flavor.



Conclusion

Value addition in flower crops is essential for the economic sustainability of floriculture. Post-harvest losses and price fluctuations reduce farmers' income when selling raw flowers. Converting flowers into products like essential oils, natural dyes, and cosmetics minimizes wastage and increases profitability.It also creates rural employment through low-investment enterprises, especially for women and SHGs, while strengthening the value chain via processing, branding,

and diversified marketing. With growing demand for eco-friendly products, value-added floriculture supports higher income, rural empowerment, and sustainable growth.

In the context of increasing demand for eco-friendly and natural products, value-added floriculture aligns with global sustainability trends. Hence, integrating value addition is essential for achieving **higher profitability, rural empowerment, and long-term sectoral growth**.

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Cissus quadrangularis: Rediscovering Nature's Orthopaedic Wonder

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K Sri Anjanidevi[1], Dr. A. Chandini Raj[2]

[1]Ph. D Scholar, Department of Plantation, Spices, Medicinal and Aromatic Crops, College of Horticulture, Dr. YSR Horticultural University, Venkataramannagudem-534101.

[2]Assistant Professor, Department of Plantation, Spices, Medicinal and Aromatic Crops, College of Horticulture, Dr. YSR Horticultural University, Venkataramannagudem-534101.

Abstract

The growing demand for sustainable nutrition, preventive healthcare and plant-based wellness has renewed interest in underutilized medicinal plants with multifunctional value. *Cissus quadrangularis*, popularly known as Hadjod or Pirandai, is one such remarkable species that integrates traditional healing, functional nutrition and climate resilience. Long revered as a "bone-healing herb," this plant possesses significance far beyond its traditional medicinal identity. Rich in bioactive compounds and valued in indigenous food systems, *Cissus quadrangularis* holds promise as a nutraceutical resource, climate-smart crop and value-added horti-food commodity. This article highlights its botanical uniqueness, nutritional and therapeutic importance, relevance in addressing contemporary health challenges and emerging role in sustainable horticulture. Rediscovering this forgotten green treasure may offer pathways toward healthier people, resilient farming systems and nature-based solutions for the future.

Keywords: *Cissus quadrangularis*, functional foods, medicinal plants, bone healer.

Introduction

In an age where farming is increasingly expected to nourish both people and the planet, attention is shifting toward plants that provide food, health and ecological resilience simultaneously. Among such species, *Cissus quadrangularis* stands out as a remarkable but underappreciated botanical resource. Known by names such as Hadjod, Asthisamharaka, Pirandai and Veld grape, this medicinal climber has occupied an important place in traditional medicine for centuries. While widely recognized for its association with bone health, the relevance of *Cissus quadrangularis* extends far beyond its reputation as a healing herb. It represents an important link between traditional knowledge and modern nutraceutical science, between food and medicine and between biodiversity and sustainable living. At a time when societies are revisiting indigenous crops, functional foods and natural health solutions, this plant deserves renewed recognition as a valuable component of future farming and food systems.

Botanical Profile

Cissus quadrangularis belongs to the family Vitaceae and is a perennial succulent climber distinguished by its characteristic four-angled fleshy stems. The segmented green stems, with well-developed nodes and internodes, give the plant a striking architectural appearance and account for the species name *quadrangularis*. The plant bears tendrils, small inconspicuous flowers and berry-like fruits, but its medicinally valued part is primarily the succulent stem. It grows vigorously under dry and semi-arid conditions and is naturally adapted to poor soils, drought stress and minimal management. Its ability to thrive under harsh conditions makes it more than a medicinal plant; it is a climate-resilient species with relevance for low-input sustainable farming.

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Importance as a Functional Food and Medicinal Plant

One of the most remarkable qualities of *Cissus quadrangularis* is its dual identity as both food and medicine. In many traditional communities, particularly in South India, it has long been used in chutneys, curries and restorative preparations, reflecting a deep understanding that nourishment and healing can coexist. This traditional culinary relevance aligns closely with modern interest in functional foods- that offer health-promoting benefits beyond basic nutrition. Rich in vitamin C, carotenoids, calcium, flavonoids and phenolic compounds, *Cissus quadrangularis* represents a natural repository of bioactive wealth.

The Legendary Bone-Healing Herb

Few medicinal plants have earned a reputation as enduring as that of *Cissus quadrangularis* in bone health. Revered in traditional medicine as the "bone setter plant," it has long been associated with support for fractures, skeletal strength and tissue recovery. Its Sanskrit name, *Asthisamharaka*, literally meaning "protector of bones," reflects this historical significance. Such traditional wisdom has sparked modern scientific interest in understanding its role in bone regeneration and skeletal wellness. In the context of increasing osteoporosis, age-related bone degeneration and musculoskeletal disorders, the plant's traditional and emerging significance makes it particularly relevant today.

Phytochemical Wealth

Its succulent stems contain a diverse range of bioactive compounds, including ascorbic acid (vitamin C), carotenoids, calcium, flavonoids, triterpenoids, stilbenes, beta-sitosterol, ketosteroids, phenolic compounds and natural antioxidants, making the plant a rich reservoir of functional phytochemicals. Ascorbic acid contributes to collagen formation, tissue repair and antioxidant defense, while carotenoids support immunity and help combat oxidative stress. The natural calcium content has often been associated with the plant's traditional role in bone health, whereas flavonoids and phenolics are valued for their antioxidant and anti-inflammatory properties. Compounds such as triterpenoids, stilbenes and beta-sitosterol further enhance its nutraceutical significance through their potential protective and metabolic supportive functions, while ketosteroids have drawn attention for their possible link with the plant's famed bone restorative properties.

Need of the Hour: Why Rediscover *Cissus* Now?

The modern world faces interconnected crises of poor nutrition, chronic disease and environmental instability. Addressing these challenges demands solutions that are affordable, sustainable and rooted in biodiversity. *Cissus quadrangularis* is uniquely positioned within this conversation. It combines therapeutic potential, nutritional relevance, climate resilience and livelihood opportunities within a single species. Rediscovering such underutilized plants is not nostalgia; it is necessity.

Value Addition

With growing markets for herbal supplements, plant-based nutraceuticals and wellness foods, the species has significant commercial potential. Stem powders, herbal extracts, functional food ingredients and nutraceutical formulations represent promising avenues for utilization. For farmers, it offers scope as a low-input medicinal crop; for entrepreneurs,

opportunities in herbal value chains; and for food systems, a candidate for innovative health-oriented products. Such possibilities position the plant not merely as a medicinal relic, but as a future-oriented food resource.

Ancient Wisdom Meets Modern Science

Long before phytochemical studies and nutraceutical industries emerged, communities had already recognized its value through practical experience. Today, modern research is increasingly validating many traditional insights associated with the plant. This intersection of heritage knowledge and scientific inquiry offers a powerful model for the future of farming and health innovation.

Conclusion

In the vast wealth of India's medicinal biodiversity, *Cissus quadrangularis* stands as a forgotten green treasure whose time has come again. More than a traditional healing herb, it represents a powerful intersection of nutrition, medicine, sustainability and innovation. Its significance lies not only in its famed role as the "bone-healing plant," but in its broader promise as a functional food, climate-smart crop and nutraceutical resource. Rediscovering this plant is not simply about reviving an ancient herb; it is about reimagining how traditional plants can contribute to future food and health systems. Sometimes the plants growing quietly along field borders hold answers to some of our greatest challenges. *Cissus quadrangularis* may be one such answer a humble green bridge between ancestral wisdom and a healthier, more sustainable future. *One plant - food, medicine, nutrition and resilience*.

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Insects on the Menu: A Sustainable Food Revolution

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Kota Sahithi Chowdary[1], Repaka Harika[1], Gopu Sushma[2]
[1]Ph. D Scholar, Indira Gandhi Krishi Vishwavidyalaya, Raipur.
[2]Ph. D Scholar, Professor Jayashankar Telangana Agricultural University.

Abstract
With global population growth and increasing pressure on natural resources, the search for sustainable food sources has become urgent. Insects, long consumed in many cultures, are gaining global recognition as an environmentally friendly and nutritionally rich alternative to conventional livestock. This article explores the role of edible insects in food security, their nutritional benefits, environmental advantages, and challenges to widespread adoption. By examining current research and global practices, it highlights how entomology is contributing to innovative solutions for a sustainable future.

Keywords: Entomophagy, Food security, Sustainable agriculture, Edible insects, Nutrition, Environmental impact.

Introduction
Edible insects are rich in high-quality protein, essential amino acids, vitamins (such as B12), and minerals like iron and zinc. Species such as crickets, mealworms, and silkworm pupae provide protein levels comparable to beef and fish (Wu et al., 2021). Studies show that insects can contain up to 60–70% protein by dry weight, making them excellent dietary supplements (Payne et al., 2016).



Environmental Benefits
Insect farming requires significantly less land, water, and feed compared to conventional livestock. For example, crickets need six times less feed than cattle to produce the same amount of protein (FAO, 2013). Insects also produce fewer greenhouse gases and can be reared on organic waste, contributing to waste reduction and circular economy practices (van Huis, 2020).

Economic and Social Impact
Insect farming presents new livelihood opportunities, particularly in rural areas. It requires relatively low investment and can be integrated into existing agricultural systems, supporting small-scale farmers and entrepreneurs (van Huis, 2020).

Challenges and Limitations
Despite their benefits, several challenges hinder widespread adoption. Cultural resistance remains a major barrier, particularly in Western societies. Additionally, allergenic risks associated with insect consumption require further research (Wu et al., 2021). Regulatory frameworks and large-scale production technologies are still under development (van Huis, 2020).

Conclusion
Insects represent a promising solution to some of the most pressing challenges in global food systems. Their high nutritional value, low environmental impact, and economic potential make them an attractive alternative to traditional

protein sources. While challenges remain, continued research, policy support, and public acceptance can pave the way for insects to become a mainstream component of sustainable diets. Entomology, therefore, plays a crucial role in shaping the future of food security and environmental sustainability.

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Chemical Counter-Intelligence: How Plants Hack Nematode Pheromones

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Sameena[1]
[1]Department of Plant Pathology, College of Agriculture, PJTAU, Rajendranagar, Hyderabad.

Summary
In the co-evolutionary struggle between plants and soil-borne pathogens, recent research has unveiled a sophisticated mechanism of semiochemical interference. Plant-parasitic nematodes (PPNs), such as the root-knot nematode, utilize a conserved class of glycolipid signaling molecules termed ascarosides. Among these, the ubiquitously secreted ascr#18 serves as a primary communication signal for the parasite. Plants have evolved to recognize these ascarosides as Nematode-Associated Molecular Patterns (NAMPs), initiating robust Pattern-Triggered Immunity (PTI) at picomolar concentrations. This facilitates broad-spectrum systemic resistance against viruses, bacteria, and fungi without the deleterious growth-defense tradeoffs typically associated with immune activation. Furthermore, plants engage in "metabolic propaganda" by sequestering ascr#18 and processing it through the peroxisomal beta-oxidation pathway to enzymatically shorten the carbon side chain, effectively converting the inductive ascr#18 into its truncated derivative, ascr#9. By actively exuding a specific ratio of ascr#9 back into the rhizosphere, the plant creates a deceptive chemical gradient that mimics high population density and triggers an avoidance response in prospecting nematodes, offering a high-precision, non-toxic framework for sustainable integrated pest management.

Introduction
Nematodes are among the most destructive agricultural pests globally, causing over $100 billion in crop damage annually. However, recent groundbreaking research reveals that plants are not just passive victims—they are active players in a high-stakes game of chemical warfare. Nematodes utilize ascarosides, a family of small signaling molecules chemically classified as glycolipids, which serve as the primary "chemical language" for roundworms. Structurally, they are composed of the sugar ascarylose (3,6-dideoxysugar) linked to various fatty acid-like side chains.

The Secret Language of Nematodes
Nematodes communicate, find mates, and control their development using ascarosides.

1. The Master Signal: Among the hundreds of ascarosides identified, ascr#18 stands out as the most abundant pheromone produced by plant-parasitic nematodes, including the notorious root-knot nematode.

2. A Beacon of Trouble: Because ascr#18 is so universally released by these parasites, it serves as a primary detection point for the plant within the soil environment.

Plants are Eavesdropping
For millions of years, plants have evolved the ability to "listen in" on their enemies' conversations by recognizing ascr#18 as a Nematode-Associated Molecular Pattern (NAMP).

1. Broad-Spectrum Immunity: When plant roots sense picomolar to micromolar concentrations of ascr#18, they trigger a broad-spectrum immune response that shields the plant from viruses, bacteria, fungi, and oomycetes alike.

2. No Side Effects: Unlike typical plant immune responses that stunt growth to divert energy to defense, ascr#18 perception allows the plant to remain healthy and strong while silently locking down its borders.

Masterful Propaganda: Turning the Tables
The interaction is remarkably complex: plants do not just listen to the worms; they actively tamper with their messages to spread deceptive signals through the soil.

1. The Chemical Edit: Once a plant senses ascr#18, it pulls the molecule into its cells and uses its internal peroxisomal beta-oxidation pathway to cleave its carbon chains.

2. Creating the Repellent: This process converts ascr#18 into a shorter variant known as ascr#9.

3. The 'Go Away' Broadcast: The plant then pumps a 10-to-1 mixture of ascr#9 and ascr#18 back into the soil. To other nematodes in the rhizosphere, this specific mixture signals that the host is already heavily overcrowded and fully infected, causing them to seek another target. By interfering with the nematodes' communication system, the plant effectively creates its own chemical repellent.

Why Ascarosides Matter?

Harnessing natural molecules like ascr#18 offers a massive leap forward for sustainable agriculture.

1. Safe Pest Control: It provides a biodegradable, non-toxic way to stimulate plant health without the use of heavy synthetic pesticides.

2. The Future of Farming: Deciphering this ancient chemical dialogue allows for the development of crops that can actively fool, repel, and outsmart their parasites.

Conclusion

The co-evolutionary struggle between plants and soil-borne pathogens has led to a sophisticated form of chemical communication. Plant-parasitic nematodes release specific glycolipid molecules known as ascarosides, such as ascr#18, which act as essential signals for their development. However, plants have evolved to "eavesdrop" these signals, recognizing them as NAMPs. This recognition triggers PTI, boosting the plant's natural defenses. The plant further protects itself by capturing these signals and using peroxisomal beta- oxidation to chemically shorten them into ascr#9, which acts as a repellent. The discovery of this "chemical counter-intelligence" provides a sustainable model for protecting crops, allowing us to develop plants that can actively outsmart their parasites.

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From Fields to Food: The Power of Deep Learning in the Agri-Food Sector

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Kisore S[1], Hanuman Anshiram Jadhav[2], V. Eyarkai Nambi[3]
M Tech student[1], PhD Scholar[2], Professor[3]
[1]Department of Food Process Engineering
[2]Department of Food Process Technology
[3]Department of Food Plant Operations, Incubation and Entrepreneurship
National Institute of Food Technology, Entrepreneurship and Management, Thanjavur (NIFTEM-T), 613005, Tamil Nadu, India.

Introduction

Feeding the world's growing population is a huge challenge we're facing today. By 2050, there will be around 9.7 billion people on the planet, but the amount of land we have for farming is actually getting smaller. And to make things worse, the weather is becoming really unpredictable, which makes it harder to grow food. At the same time, we're wasting a lot of food, our supply chains are not working very well, and people are getting more and more concerned about food safety. It's a pretty complicated situation. But here's where deep learning comes in - it's not a magic solution, but it's a really useful set of tools that can help us get more out of the resources we have.

Deep learning is a subset of machine learning that uses multi-layered neural networks to detect patterns in large datasets. Unlike older rule-based software that needed humans to spell out every condition, deep learning systems learn directly from examples. Show a model ten thousand images of healthy and diseased mango leaves, and it will learn to distinguish between them on its own. Feed it years of sensor readings from a cold storage unit, and it can predict when a batch of tomatoes is about to spoil. These capabilities - once confined to research labs - are increasingly finding their way into farms and food factories around the world (LeCun et al., 2015)(Goodfellow et al., 2016).This article explores six important areas where a type of AI element called deep learning is already having a big impact on farming and food research.

Crop Monitoring & Smart Agriculture

Farmers have always relied on their sharp eyes and instincts to check for signs of trouble in their fields, like looking for diseases on leaves, feeling the soil with their hands, and keeping an eye on the weather. But now, a new tool called deep learning is helping them do their job even better. It's not meant to replace their instincts, but to make them stronger. Special computer programs, called convolutional neural networks, can look at pictures taken by drones and satellites and spot problems like pests, nutrient deficiencies, and fungal infections in the entire field - something that would be impossible for one person to do on their own. And the best part is, these programs are really good at it, with some studies showing they can detect diseases in crops like rice and wheat with an accuracy rate of over 95% (Mohanty et al., 2016).

Artificial intelligence is not just about fighting disease; it can also help figure out how much food we can grow. By looking at things like the weather, how wet the soil is, and what happened in past harvests, we can make pretty good guesses about what will happen this time around. This is especially important in places where water is scarce. If we use water just right, we can save a lot of it and still get the same amount of food. There are already systems in place in some parts of India and Southeast Asia that help small farmers make good decisions using data. This kind of help used to only be available to big companies, but now everyone can use it (Kamilaris & Prenafeta-Boldú, 2018).

Food Processing Optimization

In today's food processing plants, things are always changing - the temperature might suddenly spike, ingredients can be different from one batch to the next, and equipment can start to wear out. But with deep learning models that have been trained on data from the production process, it's possible to catch these changes as they happen and make adjustments on the fly, before the quality of the food is affected. For example, in bakeries, special computer programs called recurrent neural networks have been used to figure out the perfect temperature for the ovens, so that they use less energy but still produce bread that's the right texture and color. This is just one way that technology is helping to make food production more efficient and consistent. By using data and computer models to monitor and control the production process, food manufacturers can reduce waste, save energy, and make sure that their products are always of high quality.(Goodfellow et al., 2016)

Machines that can see and learn are now doing jobs that are boring or hard on the body, like cutting, sorting, and packing food. These machines can handle the fact that no two pieces of food are exactly the same - for example, every fish fillet

is a little different. But a machine that has been trained well can change how it cuts and handles the food so it gets it just right.

Food Quality Inspection & Safety

For millions of years, plants have evolved the ability to "listen in" on their enemies' conversations by recognizing ascr#18 as a Nematode-Associated Molecular Pattern (NAMP).

1. Broad-Spectrum Immunity: When plant roots sense picomolar to micromolar concentrations of ascr#18, they trigger a broad-spectrum immune response that shields the plant from viruses, bacteria, fungi, and oomycetes alike.

2. No Side Effects: Unlike typical plant immune responses that stunt growth to divert energy to defense, ascr#18 perception allows the plant to remain healthy and strong while silently locking down its borders.

Masterful Propaganda: Turning the Tables

The way we normally check food quality isn't very reliable - it's mostly people using their senses to see, smell, and taste if something is okay. This method has a lot of problems - it's based on personal opinions, it's slow, and it's hard to do on a large scale. But now, deep learning is giving us a better way to do things. Computers can look at pictures of fruits and vegetables and tell if they're ripe, how big they are, and if they have any defects on the surface - and they can do all this faster and more accurately than people can(Zhang et al., 2014).

Finding contaminants in food is just as important - it's a big deal for keeping people healthy. Some new computer programs can look at special pictures of food and find problems that we can't see. These problems can be things like foreign objects, bad mould, or tiny germs that make food go bad. These computer programs are already being used in big factories that process lots of grains, chicken, and dairy products (Jiang et al., 2022).The general pipeline of a Convolutional Neural Network (CNN), showing feature extraction and classification stages shown in Figure 1.

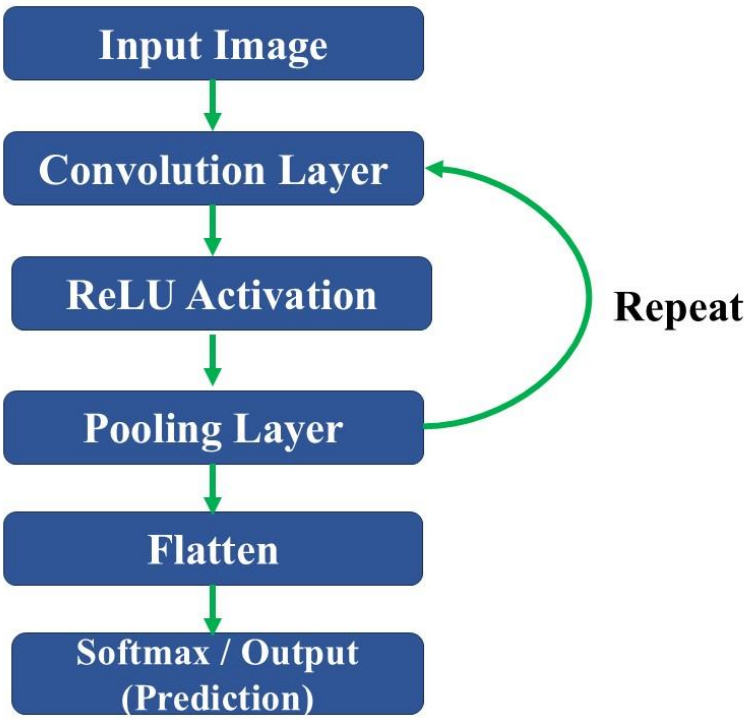


Figure 1 General pipeline of a Convolutional Neural Network (CNN) showing feature extraction and classification stages

Shelf-Life Prediction & Supply Chain

A lot of food goes to waste, and this happens for many reasons. Sometimes, food spoils before it even reaches the people who want to eat it. To fix this problem, people are using a special kind of computer program called deep learning. This program helps at many points where food is handled, from the farm to the store. It uses special models that look at things like how cold or warm it is, how humid it is, what gases are around, and how fast tiny living things like microbes are growing. With all this information, the program can tell how long the food will stay good. This is really helpful because it tells the people sending out the food which ones to send first, so they don't get spoiled on the way. This way, less food gets wasted, and there's less chance of selling food that's gone bad. It's a big deal because so much food is wasted - about one-third of all the food made worldwide. If we can make even a small change, it could make a big difference in how much food we waste and how much people have to eat. (Quan et al., 2021).

At the logistics level, deep learning-powered demand forecasting tools help retailers and distributors order the right quantities at the right time. Combined with real-time tracking and dynamic routing algorithms, these systems can substantially cut the cold chain losses that are especially acute in developing countries where infrastructure remains limited

Food Composition & Adulteration Detection

Food fraud is a big problem - it's when people deliberately mess with food products or label them wrongly. This costs the world a lot of money, billions of dollars every year, and it's also really bad for people's health. But there's a way to catch these fraudsters, and it's by using a type of computer learning called deep learning. When you combine this with special tools like near-infrared spectroscopy and Raman spectroscopy, it becomes a really powerful way to figure out what's going on. These tools can help us tell if food is genuine or not, and that's a big deal (Tsiknakis et al., 2021).

Artificial intelligence can now help figure out if olive oil is real or not, and if honey really comes from where it says it does. It can even tell what kind of fish is in a product. Before, we had to use expensive lab tests to do this. But now, with AI, it's faster and cheaper, so even small producers and regulators can use it to test things regularly.

Sensory Evaluation & Smart Sensing

Measuring the flavor of something is really tough to do in a way that's objective. Right now, the best way to figure out what something tastes like is to have a group of people try it and tell you what they think. But this method has some problems - it can be expensive, the results can vary a lot from one group to another, and it's not something that can be easily scaled up. Luckily, new technologies like deep learning are making it possible to create electronic systems that can detect the smells and tastes of foods. These systems, often called e-noses and e-tongues, are getting better and better at identifying the different compounds that make up the aroma and taste of a food.(Viejo et al., 2018)

When special computer programs are used to look at the raw data from sensors on devices, they can tell what kind of food it is, where it's from, and how good it is. They can even guess how much people will like it and find problems with the taste that might mean it's gone bad. Some wineries, coffee makers, and dairy farms are already using these tools to make sure their products are always the same, which is important because small differences in taste can make a big difference to the people buying them.(Zeevi et al., 2015).

Conclusion

Deep learning is already a part of the agri-food sector; it's not something that's going to happen in the future. We're seeing things that used to sound like science fiction, like drones that can spot sick plants and computers that can tell you what to have for breakfast, being used right now. These new technologies are helping farms grow more food, factories work smarter, and supply chains cut down on waste, all while making our food safer to eat. There are still some big problems to solve. For one, it's hard to find good quality training data in many areas of food science. Also, the computers needed to run these big models are not easy for small food producers or regulators in developing countries to access. And then there's the issue of transparency - when an AI system says a batch of food is not safe, it's important that humans can understand why it made that decision and trust it. Addressing these challenges will require collaboration between food scientists, engineers, policymakers, and the communities most directly affected by food system failures. Done well, the integration of deep learning into agri-food systems could be one of the most consequential contributions of artificial intelligence to human well-being in the coming decades.

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Zinc Nutrition in Apple Orchards of Kinnaur, Himachal Pradesh: Deficiency Status, Causes and Management

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Dr. Arun Kumar[1]

[1]Scientist (Fruit Science), Krishi Vigyan Kendra Kinnaur, Regional Horticultural Research & Training Station Sharbo, Kinnaur (HP).

Apple (*Malus x domestica* Borkh) cultivation is the economic mainstay of Kinnaur district, Himachal Pradesh, spanning the Nichar, Kalpa and Pooh development blocks across altitudes of 1500–3600 m amsl. The district produces premium-quality apples recognized at par with international export standards. Among the various factors limiting productivity, micronutrient deficiencies particularly zinc (Zn) rank as the most visually prominent and agronomically significant nutritional disorder encountered in Kinnaur orchards. Zinc deficiency is endemic across all three blocks and manifests in its most damaging form as progressive shoot die-back and branch death that can extend to the central leader, effectively rendering individual trees or sections of the orchard non-productive. Zinc is indispensable to apple tree physiology. It serves as a cofactor for enzymes regulating carbohydrate metabolism, protein synthesis, and the biosynthesis of the growth hormone auxin (indole-3-acetic acid). Disruption of auxin synthesis directly impairs apical shoot elongation, producing the characteristic little-leaf and rosette symptoms at shoot tips. Zinc is also essential for chlorophyll synthesis, making it critical at bud break when trees emerge from dormancy. The following account synthesises nutritional survey data from two major studies in Kinnaur Sharma *et al*. (2018), covering 82 orchards, and Kumari (2020), covering 30 orchards, alongside field observations and extension experience, to examine the deficiency problem and provide practical, evidence-based management guidance.

Zinc Status in Kinnaur Apple Orchards

Soil and leaf zinc surveys confirm that zinc deficiency or marginal zinc status is widespread across Kinnaur. In the survey by Sharma *et al*. (2018), DTPA-extractable soil zinc ranged from 0.50 to 4.90 ppm (mean 2.37 ppm) across the district. While the nominal optimum is 0.8–4.0 ppm, a high coefficient of variation (42%) and the large proportion of orchards in the lower range, particularly in Nichar block (mean 2.29 ppm, CV 50.5%), indicate that the soil zinc pool is spatially unreliable and frequently insufficient. Leaf zinc ranged from 11 to 46 ppm (mean 26.6 ppm), with 4.9% of orchards deficient (below 20 ppm) and a further 20.9% in the low category (20–25 ppm). Deficiency incidence was highest in Nichar block where 16.6% of orchards were deficient. Even in Pooh block, despite higher soil zinc values, 25.9% of orchards showed low leaf zinc, reflecting restricted uptake under alkaline pH and intermittent moisture stress. The 2019 survey by Kumari (2020) of 30 Starking Delicious orchards found leaf zinc ranging from 12.51 to 82.12 ppm (mean 36.40 ppm, CV 47.5%), with 5% of orchards in the low category and 95% in the medium range. The persistently high variability underscores the heterogeneous and unpredictable nature of zinc nutrition across the district.

Table 1. Block-wise Zinc Status in Kinnaur Apple Orchards (Sharma *et al*., 2018):

Block	Soil Zn Mean (ppm)	Leaf Zn Mean (ppm)	Deficient (%)	Low (%)
Nichar	2.29	23.42	16.6	20.8
Kalpa	2.62	27.00	0	19.4
Pooh	2.17	29.00	0	25.9
District	2.37	26.60	4.9	20.9

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Causes of Zinc Deficiency in Kinnaur Orchards

Multiple interacting factors drive the high prevalence of zinc deficiency in Kinnaur apple orchards:

Rocky terrain and restricted rooting: The shallow, stony soils of Kinnaur physically limit root proliferation. Apple trees require an extensive root system to mine adequate zinc. When root spread is constrained by bedrock and boulders, trees may suffer zinc deficiency even in soils with nominally adequate zinc levels.

Rainfall regime and leaching: Nichar block is predominantly rainfed. Erratic monsoon behaviour creates dual risks: prolonged dry spells suppress root activity and zinc mass-flow uptake, while heavy rainfall events leach soluble zinc from the root zone before it can be absorbed. In Pooh block, scanty rainfall (< 100 mm/year) and dependence on snowmelt irrigation channels means that water scarcity during critical summer growth periods directly curtails zinc uptake irrespective of soil status.

High soil pH and phosphorus antagonism: Zinc availability decreases sharply above pH 7.0 as Zn is precipitated as hydroxides or adsorbed on calcium carbonate surfaces. Parts of Pooh block have alkaline soils (mean pH 6.94). Excessive phosphorus application, reflected in the high available P (mean 72.04 kg/ha, with values exceeding 188 kg/ha) recorded

across the district, leads to formation of poorly soluble zinc phosphates and competitively inhibits zinc uptake. High light intensity at altitude further increases the plant's demand for zinc-dependent processes.

Neglect of micronutrient management: Sharma *et al.* (2018) noted that Kinnaur orchardists are largely unaware of the importance of micronutrient applications, a practice common in other HP apple-growing districts. Organised zinc spray programmes have historically been absent in most orchards.

Canopy shading: Mature Royal Delicious and Red Delicious trees at 7 m × 7 m spacing develop dense, overcrowded canopies where inner branches receive inadequate light. Light deficiency in the interior canopy reduces photosynthetic demand and zinc utilization, while the physical barrier impedes penetration of foliar sprays to deficient inner branches, allowing die-back to progress unabated.

Deficiency Symptoms in the Field

The symptom progression of zinc deficiency in Kinnaur apple orchards follows a recognisable sequence. The earliest visible sign is the appearance of abnormally small, narrow, distorted leaves, the 'little leaf' syndrome at the tips of actively growing shoots, arising from zinc-mediated suppression of auxin biosynthesis and consequent failure of normal cell elongation. These stunted leaves are produced in tight, compressed clusters at the shoot apex, forming the characteristic rosette. Internode length is markedly reduced. Affected leaves commonly show interveinal chlorosis (yellowing between veins while veins remain green), and sometimes necrotic spotting. When deficiency persists without corrective intervention, the affected shoot tips fail to grow entirely in subsequent seasons. Apical buds remain dormant even under favourable spring conditions. The non-growing shoot tips begin to die back progressively from the tip downward, shoot die-back and the dead tissue gradually descends the branch. In advanced cases, entire scaffolding branches and ultimately the central leader are lost. Trees in this stage present dead framework wood interspersed with isolated surviving shoots, severely curtailing productive canopy area and fruit yield. These observations are consistent with reference descriptions of zinc deficiency in temperate fruit orchards and with the die-back pattern documented in Kinnaur field surveys.

Zinc Management: Recommendations for Kinnaur

Foliar application is the primary and most effective route for correcting zinc deficiency in apple, as confirmed by YSP UHF Nauni recommendations. Soil application of zinc fertilisers does not produce reliable responses in apple. The following spray schedule, drawing upon YSP UHF Nauni guidance, extension experience from Kinnaur, and the HP State Spray Schedule 2026, is recommended:

Table 2. Recommended Zinc Spray Schedule for Kinnaur Apple Orchards

Spray Stage	Product & Rate	Purpose & Remarks
Dormancy (Jan–Feb)	Zinc sulphate 2 kg + hydrated lime 1 kg per 100 L water	Corrects pre-season zinc deficit; zinc penetrates bark and accumulates as reserve. Do NOT spray within 3 weeks of pruning. Most effective single intervention.
Pink bud stage	Chelated zinc 0.3–0.5% (500 g/100 L)	Supplies zinc at critical period of flower and leaf development. Chelated form preferred, less phytotoxic than $ZnSO_4$ near flowering.
Petal fall (fungicide spray)	Metiram 70 WG as per label (700 g/100 L)	Disease management (scab) + incidental zinc supply (13–16% Zn). Complies with HP State Spray Schedule 2026.
Post-harvest (Sept–Oct)	Zinc sulphate 0.5% OR chelated zinc 0.3%	Replenishes zinc reserves after crop load. Essential for trees showing deficiency. Improves shoot zinc for next season.
Growing season only if deficiency confirmed (May–June)	Chelated zinc only, 0.3–0.5%	Chelated form mandatory during growing season, zinc sulphate causes fruit russeting. Max 1–2 sprays at 15-day interval.

Note: Always test spray on a few trees first to check for phytotoxicity. Never mix zinc sulphate with other agrochemicals unless compatibility is confirmed.

The dormancy spray deserves special emphasis. Applied when trees are fully leafless and before bud swell, zinc sulphate at 2% concentration (with lime as phytotoxicity buffer) penetrates the bark and is stored in wood tissues, providing zinc at bud burst and channelled directly to the growing meristems where it is most needed. This single intervention, if applied annually has the potential to substantially reduce the incidence of little leaf and rosette in the subsequent season. In recent years, progressive Kinnaur farmers have begun applying chelated zinc at pink bud and post-harvest stages, representing a positive shift. However, consistency of application and correct product selection remain challenges. A further, often overlooked source of zinc is metiram 70 WG, a polymeric zinc dithiocarbamate fungicide

already in routine use for scab management at petal fall in the HP State Spray Schedule 2026. Its zinc content (approximately 13–16%) means that each application constitutes a meaningful foliar zinc dose. Orchardists and extension workers should recognise this dual benefit. Similarly, Zineb and Ziram, zinc-containing dithiocarbamate fungicides were included in spray programmes, contribute to seasonal zinc supply.

Complementary Agronomic Practices

Zinc management cannot be isolated from broader orchard management. Canopy thinning through systematic annual pruning is essential to (a) improve light penetration to inner branches, improving their productivity and responsiveness to foliar sprays, and (b) ensure that zinc sprays physically reach all parts of the tree canopy including the inner framework branches most prone to die-back. Without canopy opening, foliar sprays applied to the outer leaf layer do not benefit the zinc-depleted inner branches. Soil organic matter management, through regular winter application of well-decomposed FYM, already a traditional practice in Kinnaur — should be maintained and strengthened. Organic matter improves zinc complexation and availability and supports the microbial activity responsible for mineralising organically bound zinc. Avoidance of excessive phosphorus application and maintenance of soil pH within the slightly acidic to neutral range (6.0–6.8) through careful fertiliser selection are additional soil-side measures that reduce the risk of zinc immobilisation. Annual leaf tissue analysis (samples from mid-shoot mature leaves, collected July–August) is the most reliable tool for confirming deficiency and monitoring the effectiveness of the zinc programme. Optimum leaf zinc in apple is 20–50 ppm. Trees below 20 ppm require urgent corrective treatment. Consistent leaf monitoring over two to three seasons provides the evidence base for refining spray rates and timings to match site-specific conditions.

Conclusion

Zinc deficiency is a prevalent and economically important nutritional disorder in apple orchards across all three blocks of Kinnaur district. It arises from a convergence of soil constraints, agro-climatic stresses, and long-standing management gaps, and manifests along a severity continuum from little-leaf and rosetting to shoot die-back and branch death. The disorder is tractable: a systematic zinc spray programme incorporating dormancy zinc sulphate spray, chelated zinc at pink bud and post-harvest stages, strategic use of zinc-containing fungicides at petal fall, combined with annual canopy management and organic matter maintenance, can substantially reduce its incidence. KVK Kinnaur, in partnership with the Department of Horticulture and YSP UHF Nauni, should prioritise zinc nutrition management as a central component of apple productivity enhancement programmes in the district, with farmer training, demonstration orchards, and leaf tissue analysis services as the key delivery mechanisms.

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Robotic Milking Systems: An Evaluation of Their Potential as the Future of Dairy Farming

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Aman Nain[1], Shweta[1]

[1]Research scholar, Department of Dairy Engineering, Lala Lajpat Rai University of Veterinary and Animal Sciences, Hisar, Haryana, India.

[1]Research scholar, Department of Dairy Technology, Lala Lajpat Rai University of Veterinary and Animal Sciences, Hisar, Haryana, India.

Introduction

When we look at dairy farming today, it is almost unrecognizable compared to a decade ago. Farmers once followed rigid schedules, waking before dawn to milk their cows by hand or with simple machines, relying heavily on physical labor. But the agricultural landscape is changing. Labor shortages are becoming more common, and the pressure to produce milk efficiently while keeping animals healthy has never been greater. In response, technology is stepping in, giving rise to what researchers now call precision dairy farming. This approach allows farmers to monitor individual animals in real time and amake data driven decisions (Eastwood & Renwick, 2020). The global automatic milking machines market was valued at USD 908 million in 2023 and is expected to reach over USD 1 billion by 2029. Among the most promising innovations is the robotic milking system, which is quietly but steadily transforming how milk is produced and how herds are managed around the world (Barkema et al., 2015). To better understand its impact, it is important to first look at how these systems are designed and how they function.

What are Robotic Milking Systems?

Robotic milking systems, formally known as Automatic Milking Systems, are designed to perform the entire milking process with little to no human involvement. Unlike traditional methods where farmers bring cows to the parlor at set times, these systems allow cows to decide when they want to be milked. The cow walks into a milking station voluntarily, the system identifies her, cleans her udder, attaches the milking cups, and collects the milk, all automatically (de Koning, 2010). A 2023 review analyzing 536 studies on these systems and found that most research has been conducted in Europe, focusing on milk production, animal behavior, and health disorders like mastitis (Marques et al., 2023). This shift is more than just a technological upgrade. Instead of forcing the cow to fit the system, the system is built around the cow. Once the concept is clear, the next step is to understand how the system operates in practice.

How the System Works?

Each cow wears an electronic identification tag, often a collar or an ear tag. When she steps into the robotic milking unit, the system reads her ID and checks when she was last milked. If enough time has passed, the system opens the gate and begins. Robotic arms gently clean each teat, stimulate milk let down, and attach the milking cups. Recent advances have been remarkable. Researchers have developed an automatic teat cup attachment system using visual perception technology that achieves 97.8% accuracy and takes only about 117 milliseconds to complete the process (Biosystems Engineering, 2025). Throughout milking, sensors measure milk flow, temperature, and electrical conductivity, which is an early warning sign of mastitis, a common and painful udder infection (Hogeveen & Oude Lansink, 2021). Once finished, the cups detach automatically, and the cow leaves. All of this happens without a farmer needing to touch her.

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The Intelligence behind the Technology

Beyond the mechanical process, the true strength of these systems lies in the intelligence that supports them. What makes these systems truly powerful is not just the robotics but the intelligence behind them. Sensors, machine learning, and cloud based platforms give farmers a real time window into each animal's health (Rutten et al., 2013). The European Union funded dAIry 4.0 project is advancing these systems by integrating AI tools that allow individualized milking, feeding, and health monitoring. New camera systems can now monitor health at the level of a single teat, and a decision support system helps farmers manage each cow with personalized recommendations (CORDIS, 2024). A sudden drop in milk yield or a change in conductivity can trigger an alert, allowing the farmer to check on a cow before she shows visible signs of illness. This kind of early warning was nearly impossible with conventional milking. As one farmer put it, the robot does not just milk my cows but watches over them for me.

Benefits for Farmers and Cows

For farmers, the most immediate benefit is freedom. They are no longer tied to the parlor twice a day, every day. This flexibility improves quality of life, reduces physical strain, and allows them to spend more time with their families or on

other farm tasks (Butler et al., 2012). For cows, the benefits are just as real. Being milked on their own schedule reduces stress, and less stressed cows tend to be healthier and often produce more milk. A recent study analyzing over 20,000 data points from 52 cows found that those who spent more time eating had better feed efficiency, while those with longer rumination times also showed improved milk production (Freitas et al., 2025). Continuous monitoring also means that problems like mastitis or lameness are caught earlier, leading to faster treatment and less suffering (Rutten et al., 2013).

Economic Considerations

Despite these advantages, economic feasibility remains a key consideration. There is no avoiding the fact that robotic milking systems are expensive. A single unit can cost between $150,000 and $300,000 (Barkema et al., 2015). For a small family farm with 30 cows, that kind of investment is daunting. However, research shows that farms with at least 35 to 40 cows can eventually see a return, though it may take about four years (Hansen et al., 2019). A study on Korean dairy farms found that those adopting robotic systems produced more calves, increased milk production by 2.4 to 2.9 kilograms per cow per day, and reduced labor by up to 0.3 hours per cow per week (Lee et al., 2024). Milk revenue also tends to be higher on these farms, partly because cows are milked more frequently. Still, for small scale farmers, the upfront cost remains a real barrier.

Challenges and Limitations

Along with benefits, certain limitations must also be considered. No technology is perfect, and these systems come with their own set of challenges. Farmers need training, not just to operate the robots but to interpret the data they produce (Eastwood & Renwick, 2020). In many developing regions, unreliable electricity and poor internet connectivity make it difficult to run these systems reliably (Singh et al., 2025). There is also a learning curve for the cows. Some take days or even weeks to feel comfortable walking into the robotic unit (Bach et al., 2007). And because cows see less of the farmer, some worry that subtle signs of illness might be missed.

Global Trends and the Indian Context

The adoption of these systems varies significantly across regions. In countries like the Netherlands, Denmark, Germany, and the United States, robotic milking has moved from novelty to normalcy. These nations have the infrastructure, including reliable power and high speed internet, to make these systems work at scale (de Koning, 2010). In India, however, the story is different. Adoption is still in its early stages, though interest is growing rapidly among large dairy cooperatives and progressive farmers. Organizations like the National Dairy Development Board are promoting digital tools through programs like eGOPALA and the National Digital Livestock Mission (Singh et al., 2025). For a country with millions of smallholder dairy farmers, the path to automation will not be quick or easy. But with targeted subsidies, mobile based training, and shared robotic facilities, there is real potential for gradual adoption (Barkema et al., 2015).

Future Outlook

Looking ahead, the future of robotic milking seems bright. Newer generations of robots are more reliable and easier to maintain. A study on a buffalo farm in Italy showed that switching to a newer model increased both the quantity and quality of milk produced (Verde et al., 2023). Researchers are now integrating these systems with wearable health sensors, automated feeders, and barn climate controls. The dAIry 4.0 project is even developing a farm Digital Twin that will generate real time recommendations for farmers while reducing CO_2 emissions (CORDIS, 2024). Imagine a farm where a cow's activity collar talks to the robot, and the robot talks to the feeder, and the whole system adjusts automatically to keep every animal healthy and productive. Some experts believe that within twenty years, robotic milking will be the norm in high income countries and increasingly common in middle income nations as well (Eastwood & Renwick, 2020).

Conclusion

So, are robotic milking systems the future of dairy farming? The answer seems to be yes, but with important caveats. They offer a level of efficiency, animal welfare, and data driven insight that traditional methods simply cannot match. However, they are not a magic bullet. Their success depends on farm size, infrastructure, farmer training, and financial support. For large commercial farms in developed countries, these systems are already a smart investment. For smallholders in developing nations, they remain aspirational for now. But the direction is clear. Dairy farming is moving toward automation, intelligence, and sustainability, and robotic milking systems are leading the way (Barkema et al., 2015).

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Eating for the Mountains: How Traditional Diets Support Life at High Altitudes

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Ankita Bhatt[1]
[1]Soban Singh Jeena University Campus, Champawat.

Summary

Living in the Himalayas of Uttarakhand is hard because of the rough terrain, cold weather, and high altitudes. People need diets that help them stay strong and adapt. Traditional foods are high in complex carbohydrates and proteins. As an instance, finger millet and barnyard millet provide it long-lasting energy, while black soyabean and horse gram make it easier to build muscle. Leafy greens, herbal dishes, and spices like turmeric, garlic, and ginger all assist in improving the immune system. Fermented foods are also good for gut health. Meals are full of energy and often have ghee in them. They are served warm to keep the body warm. Seasonal, locally sourced diets are a healthy alternative to modern processed foods as they are well-rounded, sustaining, and durable.

Introduction

What we see of the Himalayas from a distance often seems complete and almost certain, but reality changes when we get closer. Life in the rugged hills of Uttarakhand is shaped by altitude, cold climates, and physically demanding terrain. Survival in high-altitude environments presents significant physiological challenges, including hypoxia, extreme cold, and gastrointestinal issues. For generations, communities in regions like Kumaon and Garhwal have relied on traditional diets that are not only locally available but also perfectly suited to sustain energy, strengthen immunity, and help the body adapt to harsh mountain conditions (Bhatt and Aprajita, 2026).

Fuel for Stamina and Endurance

Despite advancements in multiple fields, life in the mountains involves steep climbs, long walks, and labor-intensive farming. To meet these energy demands, traditional diets emphasize complex carbohydrates and protein-rich foods that would make them work longer. Staples like mandua (finger millet) comprising of carbohydrate (65-75%), protein (5-13%), calcium 9344mg/100g), dietary fiber (Kazi et al., 2022) and jhangora (barnyard millet) comprising high carbohydrate (57-68.8%), dietary fiber (12.6%), protein (10.5-11.2 %) and fat (2.7-3.6%) (Ugare et al., 2014), are slow-digesting grains that provide sustained energy throughout the day. Unlike refined grains, these millets release glucose gradually, preventing fatigue and keeping the body active for longer durations. Dishes such as mandua roti or jhangora kheer are both nourishing and filling. Protein is another essential component. Locally grown pulses like bhatt (black soybean) and gahat (horse gram) are rich in protein (22- 44%) and iron (5.02-15.58mg/100g), helping repair muscles and maintain strength in physically demanding environments (Prasad and Singh, 2015; Bhartiya et al., 2020).



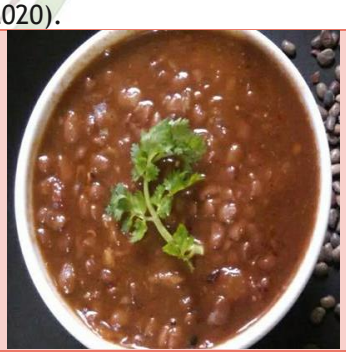
Mandua roti



Jhangora Kheer



Bhatt ki Daal



Gahat ki Daal

Building Immunity Against Harsh Weather

Cold temperatures and unpredictable weather in high-altitude regions can weaken immunity. Traditional diets in Uttarakhand incorporate ingredients that naturally enhance the body's defense mechanisms. Leafy greens such as kafuli (made from spinach and fenugreek leaves) and gethi soup (aerial yam) are packed with vitamins and antioxidants. These nutrients help fight infections, coughs, colds, and digestive issues, and maintain overall health. Additionally, spices like turmeric, garlic, and ginger, which are commonly used in everyday cooking, have anti-inflammatory and antimicrobial properties. Fermented foods like pallar (smoky buttermilk), though less widely documented, also play a role in gut health, which is closely linked to immunity. These foods introduce beneficial bacteria that support digestion and strengthen the immune system.

		
Kafuli	Gethi Soup	Pallar

Adapting to Cold and High Altitude

At higher altitudes, the body requires more calories to maintain an ideal temperature. Traditional meals are designed and combined in a balanced way to be warming and energy-dense. Foods prepared with ghee (clarified butter) provide essential fats that help insulate the body and offer a concentrated source of energy. Warm, freshly cooked meals like daals, thick gravies, and porridges are preferred over cold or raw foods, as they are easier to digest and help maintain body heat. Hydration is another key factor. While the cold may reduce the sensation of thirst, traditional diets include soups, herbal teas, and buttermilk to ensure adequate fluid intake and prevent dehydration.

Seasonal Wisdom and Local Adaptation

One of the most remarkable aspects of Uttarakhand's traditional diet is its alignment with seasonal availability. In winters, diets become warmer, richer, and heavier to combat the cold, while summers see lighter, cooling foods. This seasonal approach not only ensures nutritional balance from a variety of cereals to a variety of fruits (apricot, plum, pear, apple, peach, orange, walnuts) but also reflects a deep understanding of their importance as per the changing environment. Locally sourced ingredients reduce dependency on external food systems and promote sustainability.

In today's fast-paced world, many of these traditional practices are being replaced by processed foods. However, the wisdom embedded in Uttarakhand's mountain diet offers valuable lessons. As seen at the time of COVID-19, many therapeutic wild herbs and fruits like hemp seed, wild mustard (raai), nettle leaves, himalayan lemon (nimbu saan), raspberry, kafal (Myrica esculenta), which are rich in vitamins and antioxidants, helped people not get much affected by that virus. From nutrient-dense millets to immunity-boosting greens, these foods are increasingly being recognized for their health benefits. As interest in sustainable and functional diets grows, the traditional eating habits of Uttarakhand's hill communities stand out as a model of resilience and balance.

Conclusion

The traditional diet of Uttarakhand is more than just food. It is a survival strategy passed down over centuries. By supporting stamina, boosting immunity, and helping the body adapt to high altitudes, these dietary practices reflect a profound connection between people, place, and health. In understanding and preserving these traditions, we not only honor cultural heritage but also uncover the hidden gems of the Himalayan region and find ways to consume them in our daily lives to live in these challenging environments.

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The Invisible Shield: How Plasma Processed Air is Revolutionizing Food Safety

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Nivetha E[1], Karthick Ajay B[2], Hema V[3], Subhangi Panigrahi[4], Dr. Shanmugasundaram[5]

[1,4]Ph.D. Research Scholar, Department of Food Technology, NIFTEM-T, Thanjavur-613005.

[2]Young professional, Department of Food Plant Operation, Incubation and Entrepreneurship Management, NIFTEM-T, Thanjavur-613005.

[3]Professor, Department of Food Plant Operation, Incubation and Entrepreneurship Management, NIFTEM-T, Thanjavur-613005.

[5]Professor & Head, Department of Food Plant Operation, Incubation and Entrepreneurship Management, NIFTEM-T, Thanjavur-613005.

Abstract

Every year, millions of people contract foodborne diseases, which led the industry to implement **Plasma-Processed Air (PPA)** a room-temperature, chemical-free sanitation technique that eliminates pathogens while maintaining the flavor and texture of food. PPA is electrified air that neutralizes bacteria, viruses, and pesticides by producing **Reactive Oxygen and Nitrogen Species (RONS).** These reactive organisms degrade contaminants and pathogens without harming food when they are appropriately handled. This article provides an understandable explanation of how PPA and related plasma technologies operate, where they are currently being tested in the food chain, what benefits they offer over traditional methods, and which consumer, scientific, and regulatory obstacles still need to be removed before they are regularly used to make our food safer.

Keywords: Plasma-processed air (PPA), Cold plasma, Food safety, Reactive Oxygen and Nitrogen Species (RONS), Pathogen Inactivation, and Microbial Decontamination.

Introduction

The shortcomings of conventional sanitation techniques like heat, radiation, and chlorine-which frequently degrade food quality or leave behind dangerous chemical residues-are brought to light by recalls of "ready-to-eat" salads. (Abdalrazeq et al., 2025). The food industry has investigated "non-thermal" technologies such as cold plasma, ultrasound, pulsed electric fields, and high-pressure processing to mitigate these trade-offs (Safwa, S et al., 2023). At room temperature, pathogens, poisons, and pesticides are broken down by **Reactive Oxygen and Nitrogen Species (RONS)** produced by cold atmospheric plasma. This technology can be employed as **Plasma-Activated Water (PAW)** for washing solutions or directly as **Plasma-Processed Air (PPA)** for packing or surface treatment. Although encouraging for food safety, more study is needed to maximize both efficacy and safety. (Schnabel, U et al., 2019).

How Plasma-Processed Air (PPA) Works

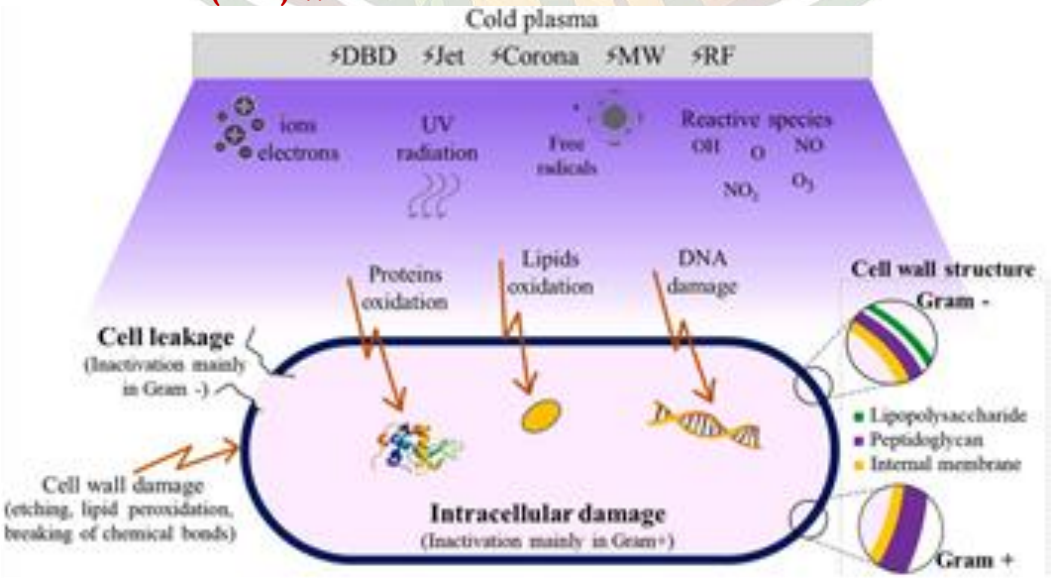


Fig 1 Fresh produce surfaces are sanitized by reactive species produced by cold plasma discharge (Jadhav, H.B et al., 2024)

What are RONS and Why do they Matter?

Transient Reactive Oxygen and Nitrogen Species (RONS) such as O_3, OH, H_2O_2, and NO are produced by plasma-processed air and disinfect food by damaging microbial membranes, DNA, and proteins. Because they immediately disperse after neutralizing infections, these species are extremely effective without leaving any hazardous leftovers.

Applications of PPA and Related Plasma Technologies

Despite being a particular configuration, "plasma-processed air" belongs to a larger family of cold plasma and plasma-activated media technologies. When combined, they already show promise for a large portion of the food supply (Bayati, M et al., 2024).

Fresh Produce and Leafy Greens

The wet surfaces and cut edges of fresh food, especially leafy greens, create a perfect home for infections like *Salmonella, E. coli, and Listeria*. Conventional chlorine washes can leave behind unwanted chemical residues and frequently fail to reach microorganisms concealed in tiny cracks (Aryal, J et al., 2024). Without sacrificing texture or nutritious phenolic value, cold plasma treatments like Plasma-Processed Air (PPA) successfully disinfect leafy greens and sprouts by lowering microbe counts by 90–99.9% (1-3 log) (Özdemir, E et al., 2023).

Meat and Poultry

The primary causes of foodborne illness worldwide are raw meat and poultry. Here, we are studying both plasma-activated media such as PPA and PAW and direct surface cold plasma, including in-package devices. PPA can be used on carcasses, slices, or packaged goods to sanitize surfaces without requiring a lot of heating while preserving the texture and color of meat. However, meat's high protein and fat content can also make it more susceptible to lipid oxidation, which could cause discoloration and odd tastes if RONS exposure is prolonged or severe (Varilla et al., 2020).

Grains, Seeds, and Nuts

Grain goods, seeds, and nuts frequently contain molds, mycotoxins (such aflatoxins), and chemical residues. These products are relatively dry and often held for long periods of time, making them attractive candidates for gas-phase treatments like PPA. (De Oliveira, A et al., 2025). For plant-based foods generally, atmospheric cold plasma has been used to degrade mycotoxins and pesticide residues on cereals, pulses, and seeds in addition to altering enzymatic activity and sometimes enhancing functional characteristics like hydration or extraction yields (Liu et al., 2025).

Liquid Foods and Plasma-Activated Water

In order to produce Plasma-Activated Water (PAW), an acidic, oxidizing solution that contains species such as H_2O_2, nitrites, and nitrates, plasma-processed air can be bubbled through water. Research is being done on this adaptable medium for treating or thawing meat and seafood, cleaning eggshells, and washing fruit. (Han, Q et al., 2021). Using PPA as the controlled generator for the reactive solution, PAW washing of fruit and rocket leaves decreases microorganisms by 90–99.9% while maintaining quality and prolonging shelf life (Liu, C et al., 2021).

Packaging and Contact Materials

Sanitizing food contact surfaces and packaging is another potential use for PPA. To inactivate bacteria, lessen biofilms, or even change surface chemistry to enhance barrier or adhesion qualities, plasma-processed air can be applied to the inside surfaces of plastic sheets, cartons, or conveyor belts (Schnabel, U et al., 2018). PPA may naturally fit into high-throughput packing lines, providing on-demand disinfection without the need to store and handle huge volumes of liquid sanitizers because it can be turned on and off fast and operates at near-ambient temperatures. This helps achieve sustainability goals by lowering the risk of chemical residues and limiting water use (Zou, F et al., 2025).

Advantages Over Conventional Food Decontamination Methods

For many years, the food sector has relied on the same fundamental decontamination processes. For liquid foods, thermal pasteurization-which was first used in the 19th century remains the gold standard. When washing fresh vegetables, chemical disinfectants such peracetic acid and chlorine are frequently used. While some uses of radiation, such as those using gamma rays or electron beams, are permitted, customers in many marketplaces fiercely resist it. The benefits of PPA are strong in light of this (Wang, J et al., 2022).

Conclusion

By employing electrified air to get rid of pesticides and pathogens without sacrificing quality, plasma-processed air (PPA) provides an advanced, chemical-free substitute for conventional food sanitation. PPA is positioned to supplant traditional techniques like chlorine rinses and become a common, "invisible" instrument for guaranteeing food safety in the upcoming decades as researchers and regulators strive to scale this technology and create safety regulations.

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Alternative Proteins and Future Food Systems: Technological Advancements, Sustainability Implications and Market Transitions

Article ID: 73615

Gopakumar Pillai[1], Vaidehi Iyengar[1], Vipul Sharma[1]

[1]Department of Biotechnology, Pillai College of Arts, Commerce and Science (Empowered Autonomous), New Panvel, Navi Mumbai, Maharashtra, India.

Abstract

Expanding global population, climate change and the depletion of global resources have been putting stress onto current supply chain systems. With this in mind, Alternative Proteins have become not only an area of research but now also have transitioned into a priority area for businesses as well. Plant-based alternatives (like plant-based meats), fermented foods, insects, and cultured meats are all good options for traditional animal proteins. They all have a much smaller effect on greenhouse gases, land use, and water use than traditional livestock proteins. For example, research has shown that plant-based meat alternatives can cut greenhouse gases by up to 91% compared to regular beef, which has caught the attention of both investors and policymakers. APs accounted for approximately $26.4 billion USD (2025) worth of AP sales globally and are projected to grow to $109.6 billion (2035). Despite this anticipated explosive growth, there are still a number of significant barriers that will have to be overcome; for instance, consumer resistance toward trying APs, lack of uniform regulations across countries, production challenges to scale APs adequately for market demands, and comparison of the nutritional value of APs with other types of protein. The following review evaluates research available today in the areas of nutritional value of Alternative Proteins, production processes, sustainable practices used to produce them and how APs fit into the marketplace.

Keywords: Alternative Proteins, Plant-based Meat, Precision Fermentation, Insect Protein, Life Cycle Assessment.

Introduction

According to experts, almost 73% growth in global demand for meat will occur due to increase in world population to around 10 billion people by 2050 while about 1/3 of total greenhouse gases produced today come from agrifood systems. Conventional agriculture occupies roughly The agricultural sector is predominantly composed of conventional agriculture (approximately 77% of total agricultural land), contributing a mere 18% of the world's total intake; therefore, conventional agriculture produces significant pollution, declines in freshwater supplies and decreases in biodiversity.002077% of agricultural land yet supplies only 18% of global intake, generating substantial pollution, freshwater depletion, and biodiversity loss. These factors render current protein supply systems ecologically unsustainable.

A Multiple Development Goals or Sustainable Development Goals are addressed directly by the transition to Alternative Proteins. This shift addresses Zero Hunger, Responsible Consumption, and Climate Action. The Protein Transition is not merely a change in diet but is a comprehensive transformation of Agri-Food systems calling for technological innovation, regulations to be modernized, and consumer behaviour to be changed to facilitate this transition. This review seeks to provide an overview of the current development state of alternative proteins, classified by the following categories, with a focus on the nutritional content; processing technologies, and environmental attributes within each category, as well as commercial viability or potential.

Classification of Alternative Proteins

Plant Based Proteins: In regard to Plant-based proteins, these are derived from Soy, Pea, Wheat Gluten and Plants (Lentils, Mung Beans) - represent the most commercially advanced Alternative Protein category (i.e., roughly 60-70% of Global Alternative Protein Market)currently approved for sale by national regulatory bodies. Plant-based proteins, derived from soy, pea, wheat gluten, lentils, and mung beans, represent the most commercially mature AP category, accounting for ~60–70% of global AP market share. Big changes in diets toward plant-based meat and dairy alternatives could have big benefits for the climate and biodiversity by using less land and producing less gas.

Microbial and Fermentation Derived Proteins: Microbial proteins include mycoprotein (e.g., *Fusarium venenatum*), single-cell protein, and precision fermentation-derived ingredients like animal-free casein, whey, and ovalbumin. Mycoprotein currently accounts for about 45% of the fermentation-based AP segment, and patent filings are steadily increasing. Precision fermentation offers a way to get similar dairy and egg proteins without using animals, but bioprocess scalability and downstream processing costs are still the main issues.

Insect Based Proteins: Insect proteins, particularly black soldier fly (*Hermetia illucens)*, mealworm (*Tenebrio molitor*), and house cricket (*Acheta domesticus*) offer 40–70% protein on a dry weight basis alongside valuable micronutrients and bioactive lipids. Growing insects on organic waste streams is in line with models of a circular bioeconomy. The global

insect protein market is expected to grow from USD 0.5 billion (2024) to USD 2.5 billion by 2033, though food selectivity remains a significant adoption barrier in Western markets.

Cultivated (Cell Based) Proteins: Scientists create cultivated meat by taking muscle stem cells from an animal, growing those in nutrient-rich bioreactor type vessels, and converting the cells into structured muscle tissue without causing harm to the animals. Some of the biggest technological problems are the cost of growth media, scaling up bioreactors, and coming up with new designs for making three-dimensional tissue. By developing a low-cost method of producing continuous quantities of cultivated meats (approximately $6.20/lb), scientists project that all animal free media will decrease the cost of producing cultivated meats from current estimates of the cost of $300000/kg down to a commercially viable level.

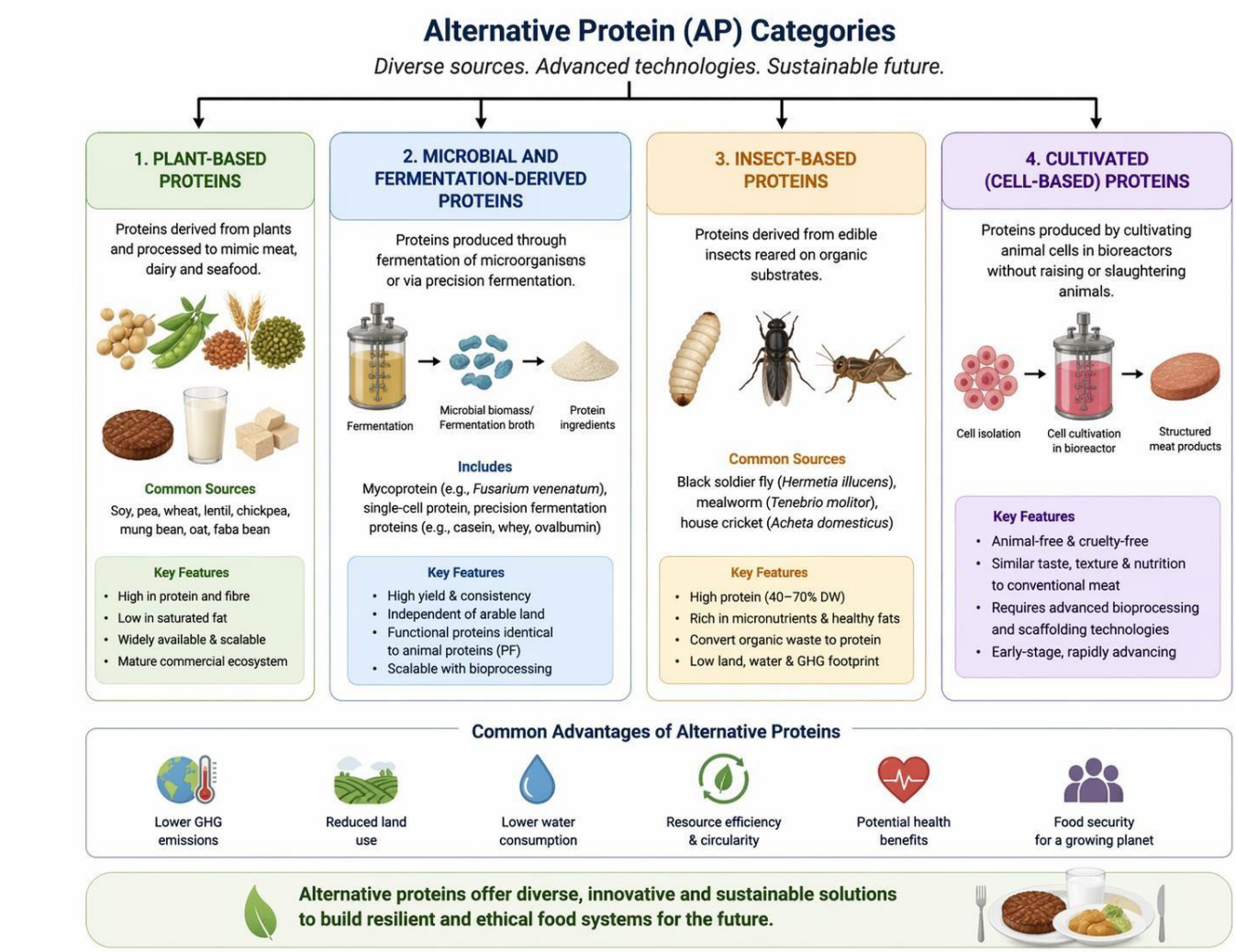


Figure 1. Schematic representation of alternative protein (AP) categories

Table 1: Comparison of Alternative Protein Sources: Nutritional and Environmental Profiles:

Protein source	Protein (%DW)	Limiting AA	GHG vs. beef	Key reference
Soy protein	36–56%	Methionine	~91% lower	[3]
Pea protein	22–30%	Met, Cys	~85–90% lower	[12]
Mycoprotein	~45% DW	Low ANFs	~88% lower	[6]
Insect (BSF)	40–70% DW	Relatively complete	~80% lower	[9]
Cultivated meat	~18–22% WW	Complete profile	~78–92% lower	[11]
Precision fermentation	>80% isolate	Customizable	~60–85% lower	[7], [8]

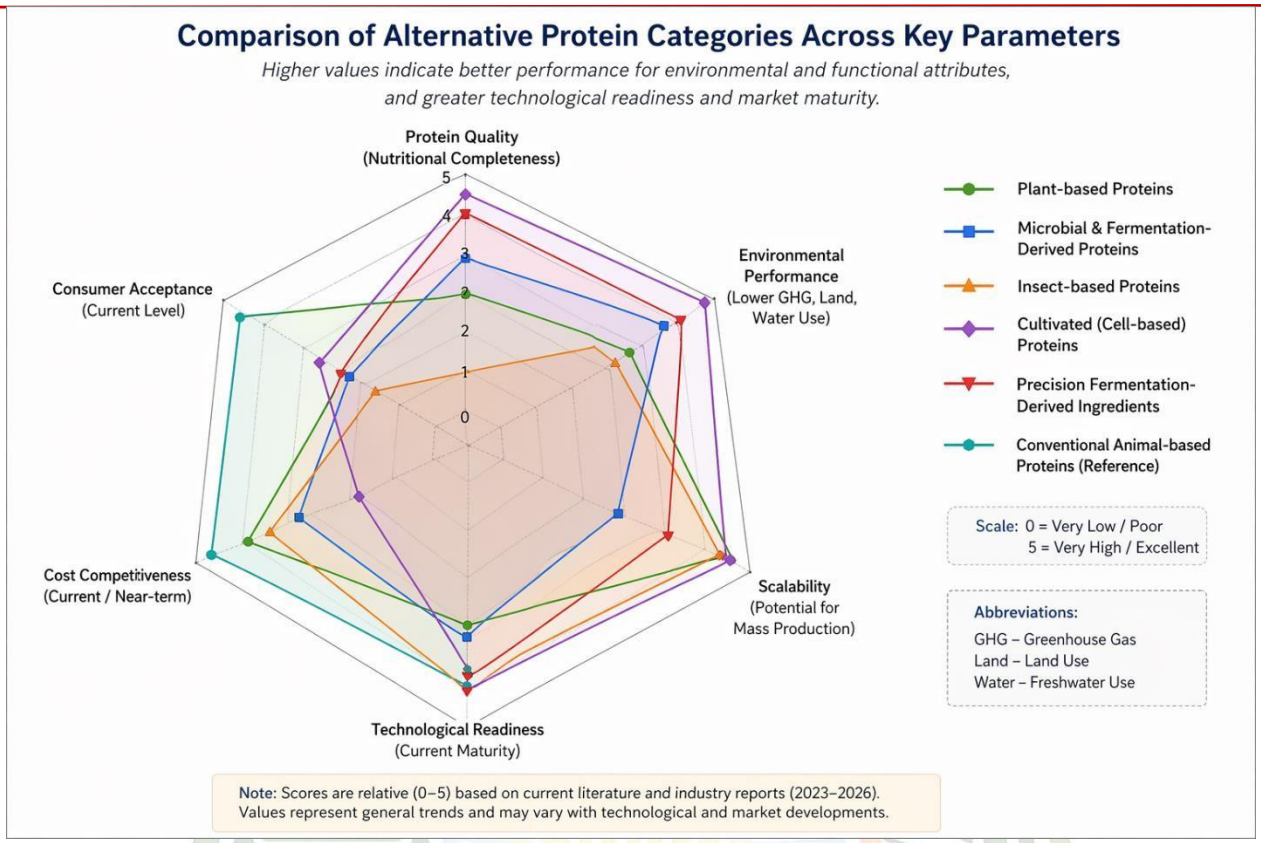


Figure 2. Comparative radar chart of alternative protein categories

Nutritional and Functional Attributes

Protein source quality determinates include protein digestibility and protein usefulness. Animal protein sources provide the most digestible and useful protein sources versus plant protein sources. This difference is attributed to the presence of less amino acids in most plant protein foods versus their animal protein counterpart and the cellular structure of plant foods makes it more difficult to digest and utilise the protein. Soy only has methionine, pea has methionine and cysteine, and wheat gluten has lysine. However, blending or fortifying these foods can make up for these deficiencies [12]. Plant-based diets are void of vitamin B12, contain poorly bio-available iron because of the possible interference of phytates with iron absorption, and contain ALA omega-3 but possess no other forms of omega-3 that could easily convert into essential EPA and DHA.

Plant foods contain ANFs that decrease the digestibility of food and mineral absorption. ANFs such as phytates, trypsin inhibitors, and lectins are ANFs that contribute to poor protein digestibility and poor mineral absorption. However, with proper methods of preparation such as soaking, extrusion, and fermentation, the activities of ANFs can be significantly diminished [13]. Gelation, emulsification, and water holding capacity are also important functional attributes for formulating meat alternatives and dairy products using plant proteins. In addition, through precision fermentation, proteins can be engineered to possess functional properties optimized for use in various food matrices [14, 15] .

Processing technologies must also be taken into account when looking at the nutrient content of a product, added food additives, and how the degree of processing may affect the nutrients in that product. Beyond nutrition, the gelation, emulsification and the water holding capacity of plant proteins are important functional attributes used in meat and dairy analogues produced using plant proteins [14]. Proteins produced using precision fermentation can be genetically engineered to provide a profile of functional properties that improves their functional performance in specific food matrices. [15].

Sustainability and Environmental Impact

According to an ISO standardised Life Cycle Assessment, meat alternatives from plants yield ~91% lower greenhouse gas emissions compared to beef, ~88% lower than pork, ~71% lower than chicken. Differences are primarily driven by avoided enteric fermentation, land conversion for feed crops, and manure management, that are the structural features of conventional livestock systems [19]. In large-scale situations, switching to plant-based meat and dairy alternatives could help restore ecosystems on large areas of farmland while still providing enough nutrition [4].

Life cycle assessments (LCAs) for plant protein concentrates and isolates often don't take into account all of the social and nutritional effects, such as the energy intensity of processing and the protein delivery adjusted for bioavailability

[20]. Standardization of LCA functional units and system boundaries can be used to enable novel cross-study comparisons, underscoring that environmental credentials require sensitive analysis as the sector scales up [21].

Market Trends and Economic Analysis

APs could make up 11–22% of the total protein market by 2035. North America is currently the leader in plant-based retail sales (USD 28.6 billion, 2024), while Asia-Pacific is the fastest growing region, with an estimated annual growth rate of ~33% (2023–2027) [22, 23]. This is due to urbanization and established plant-based food cultures. There are many reasons why people buy AP, but health, environmental concern, and animal welfare are the most important ones. The decline in production costs is just as important as the rise in price competitiveness [2]. Continued investment in precision fermentation, cellular agriculture, and mycoprotein platforms shows that people still believe in the long-term fundamentals of the market, even though it has corrected from speculative 2021 peaks [24].

Table 2: Global Alternative Protein Market Trends and Projection:

Segment / region	Current value	Projected value	CAGR	References
Global AP market	USD 26.4B (2025)	USD 109.6B (2035)	~15.3% CAGR	[22], [23]
Plant-based retail (global)	USD 28.6B (2024)	—	~60–70% AP mkt share	
Asia-Pacific AP market	—	—	~33% CAGR (2023–2027)	
Insect protein market	USD 0.5B (2024)	USD 2.5B (2033)	Fastest growth EU & Asia	[9]
Cultivated meat	Pre-commercial	—	~15% CAGR; USD 6.20/lb. target	[11]

Consumer Acceptance and Challenges

Sensory properties, particularly texture, mouthfeel, and flavor, remain the primary determinants of purchase intent for AP products [16, 17]. Persistent gaps in replicating the complex mouthfeel of fatty cuts and Maillard reaction flavor compounds continue to limit mainstream adoption. The perception of food selectivity with regard to cultivated meats and insect protein systems varies. Consumer acceptance is influenced by multiple variables, including: framing, label strategies, and cultural context [9]. While there has been a reduction in cost to produce these foods, economic cost is still a barrier for purchase by consumers of little economic means. Hybrid meat products (combination of plant and meat protein), can potentially create a solution to the sensory and economic barriers that exist while stimulating consumers to transition to these meat alternatives. Resolving scaling economics, navigating regulatory approval, and demonstrating long-term nutritional equivalence are the principal challenges that are being faced by the sector [16, 17].

The varying international approaches to regulatory frameworks for alternative proteins signify a major determinant of both market access and consumer confidence in the products. The process for approval of products from cultivated meat and ingredients derived from Precision Fermentation is particularly complicated due to the various levels of Safety Assessment, Labelling Standard requirements and Novel Food classifications that exist from region to region [10, 18]. The appropriate usage of labelling terms (such as "milk" and "meat") for plant-based and cell-based products continue to be a key area of contention as Conventional Food Industry participants regularly oppose the use of these terms in order to distance themselves from the use of common colloquial terms that may suggest an equivalence between their products and the products of nonanimal sources [16]. Addressing these regulatory challenges while developing scalable economic models and demonstrating comparable long term nutritional value continue to be the significant challenges that need to be overcome in order for the Alternative Protein Industry to realize its potential [2, 16, 17].

Conclusion

Alternative proteins offer a technically credible and commercially viable pathway to decouple human nutrition from the environmental burden of traditional livestock systems. The environmental case is strongly supported by Life Cycle Assessment evidence, the nutritional case with targeted fortification strategies, and the market trajectory at a projected annual growth rate of 15.3% by 2035 [4, 12, 19, 22, 23]. In order for the agricultural sector to reach its maximum potential, there must be a coordinated transformation in consumer acceptance and regulatory clarity that enables the economies of scale among the four alternative protein types: plant-based, fermentation-derived, insect-based and cultivated meat. The multi-source protein strategy will provide the opportunity for a sustainable and location-specific protein supply to meet future food security requirements without surpassing the resources of the planet to accommodate a growing global population. [2, 15].

Future Outlook

The continuing rise of digital technology advances, food science advances, and new regulatory frameworks will significantly influence how alternative proteins (APs) are produced. The use of AI in food product design is changing the way products are formulated by providing composition options based on the prediction of flavour, texture, and functional

characteristics of the ingredients being used. AP product development could be reduced dramatically and consumers may find AP products (compared with animal protein products) will provide better tasting food, increasing acceptance of AP products by consumers.

The concept of personalized nutrition represents a major paradigm shift for APs from generic replacement products to more specific products for a specific clientele. Nutritionally targeted protein products could be developed using knowledge gained from nutrigenomics and gut microbiota research to develop a product that is tailored to improve the individual's need for amino acids and, as a result, increase the digestibility and/or functional health benefits of the individual.

In order for this new category of protein to grow, policies and regulations will play a vital role. To establish consumer confidence creating clear rules for the assessment of safety, labelling requirements and approval processes for new sources of protein such as cultivated meat and ingredients produced using biotechnology from precision fermentation will be essential. Additionally, if government support is made available through incentives and funding, and creating policy that is directed towards sustainability, the resultant increase in affordability of the product could lead to a more rapid acceptance of alternative protein products into the market.

These changes will make alternative proteins an important part of future sustainable and resilient food systems.

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Turning Waste into Wealth: The Future of Whey Utilization

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Shweta[1], Aman Nain[1]

[1]Research scholar, Department of Dairy Technology, Lala Lajpat Rai University of Veterinary and Animal Sciences, Hisar, Haryana, India.

[1]Research scholar, Department of Dairy Engineering, Lala Lajpat Rai University of Veterinary and Animal Sciences, Hisar, Haryana, India.

Introduction

Global milk production reached 944 million tonnes in 2023, with India as the world's largest producer (Ntuli et al., 2023). A substantial proportion of Indian milk is utilized for traditional products such as paneer, yogurt, and cheese. Concomitant with this production is the generation of whey, the pale green liquid residual following milk coagulation. Historically, whey has been treated as a non-valuable by-product and discarded as waste (Rafiq & Rafiq, 2019). The Indian dairy sector generates substantial volumes of whey containing 0.4–0.6% (w/v) whey proteins that remain largely unutilized (Arora & Mali, 2025).

Globally, approximately 180-200 million tonnes of whey are produced annually, with about 9 litres generated per 1 kg of cheese manufactured. For decades, prevailing practice was to dispose of whey without treatment due to perceived lack of economic value (Marwaha & Kennedy, 1988). However, modern dairy science has reevaluated this perspective. Whey is now recognized as a valuable resource owing to its nutritional composition and industrial potential (Zandona et al., 2021; Selmi et al., 2025). The global whey market continues to expand, driven by increasing consumer awareness regarding protein consumption and applications in functional foods, sports nutrition, infant formula, and pharmaceuticals (Fortune Business Insights, 2026).

Nutritional Composition and Health Benefits

Whey comprises approximately 93% water, with total solids containing lactose (70-72%), proteins (8-10%), and minerals (12-15%) (Gupta, 2008). The protein fraction includes ß-lactoglobulin, α-lactalbumin, immunoglobulins, and lactoferrin (Rafiq & Rafiq, 2019). Whey proteins demonstrate exceptional nutritional quality, with a biological value of 104 and net protein utilization of 95, ranking next only to egg protein (Hong, 1983).

The mineral profile includes potassium, calcium, magnesium, and phosphorus, supporting cardiovascular and bone health (Gupta, 2008). Whey also contains water-soluble vitamins including riboflavin (B2) and pyridoxine (B6). Whey-derived peptides demonstrate bioactive properties supporting muscle recovery and immune modulation (Davies et al., 2018). The high content of branched-chain amino acids renders whey particularly suitable for sports nutrition and clinical applications (Peeling et al., 2018; Peeling et al., 2019).

Applications for Whey

Food Industry Applications: Whey protein concentrates (WPC, 35-80% protein) and whey protein isolates (WPI, ≥90% protein) are produced via ultrafiltration (Gupta & Reuter, 1987). These serve as functional ingredients in dairy products (cheese, cream cheese, processed cheese), beverages (fermented drinks, protein-enriched formulations), and bakery products as replacements for non-fat dry milk (Caric, 1994; Gupta, 2008).

Non-Food Applications: Whey protein films exhibit excellent oxygen and aroma barrier properties for edible coatings (Zandona et al., 2021). Whey-based bioplastics contribute to sustainable packaging (Sar et al., 2022). Whey lactose serves as a substrate for bioethanol production; the Gujarat Co-operative Milk Marketing Federation (GCMMF) in India successfully produced bioethanol from whey with 96.71% ethanol content. Whey also serves as a cost-effective substrate for pharmaceutical and biotechnological applications (Mukherjee et al., 2023).

Production Technologies

Modern membrane technologies have revolutionized whey processing. Ultrafiltration (UF) remains the most widely adopted process for recovering soluble whey protein concentrates, employing synthetic membranes for continuous operation (Jayaprakasha, 1992; Gupta & Reuter, 1987). Reverse osmosis (RO) enables pre-concentration, while multi-effect evaporators concentrate whey to 35–50% total solids (Caric, 1994).

Additional technologies include heat precipitation (heating acid whey to ≥90°C for ≥10 minutes), ion exchange adsorption (yielding products with up to 95% protein), and enzymatic hydrolysis (improving solubility, emulsifying ability, and foam stability) (Gupta, 2008; Selmi et al., 2025).

Environmental and Economic Importance

Whey is characterized by high biochemical oxygen demand (BOD: 30–50 g/L) and chemical oxygen demand (COD: 60-80 g/L) due to lactose (4.5-5.0% w/v) and soluble proteins (0.6-0.8% w/v) (Marwaha & Kennedy, 1988; Zandona et al., 2021). When released untreated, whey depletes dissolved oxygen, harms aquatic life, alters soil structure, and reduces crop yields (Selmi et al., 2025).

Only 50–60% of global whey production is effectively valorized, while 40-50% remains untreated or used for low-value applications. Only an estimated 25% of whey is used for direct human consumption (Sar et al., 2022). This underutilization represents both environmental burden and missed economic opportunity. Whey derivatives command premium prices in global markets, enabling dairy operations to transform disposal costs into revenue streams (Zandona et al., 2021; Fortune Business Insights, 2026).

Future Prospects and Conclusion

Global whey volume is expected to rise to 203-241 million metric tonnes by 2030, with an estimated yearly increase of 1-2% (Raimondo et al., 2025). Whey has transformed from an environmental liability to a valuable resource across food, pharmaceutical, and industrial sectors (Zandona et al., 2021; Selmi et al., 2025). The nutritional superiority of whey proteins positions whey as a strategic ingredient for functional foods (Davies et al., 2018). Modern membrane technologies enable efficient recovery and fractionation of whey components, supporting circular economy models (Gupta & Reuter, 1987; Jayaprakasha, 1992).

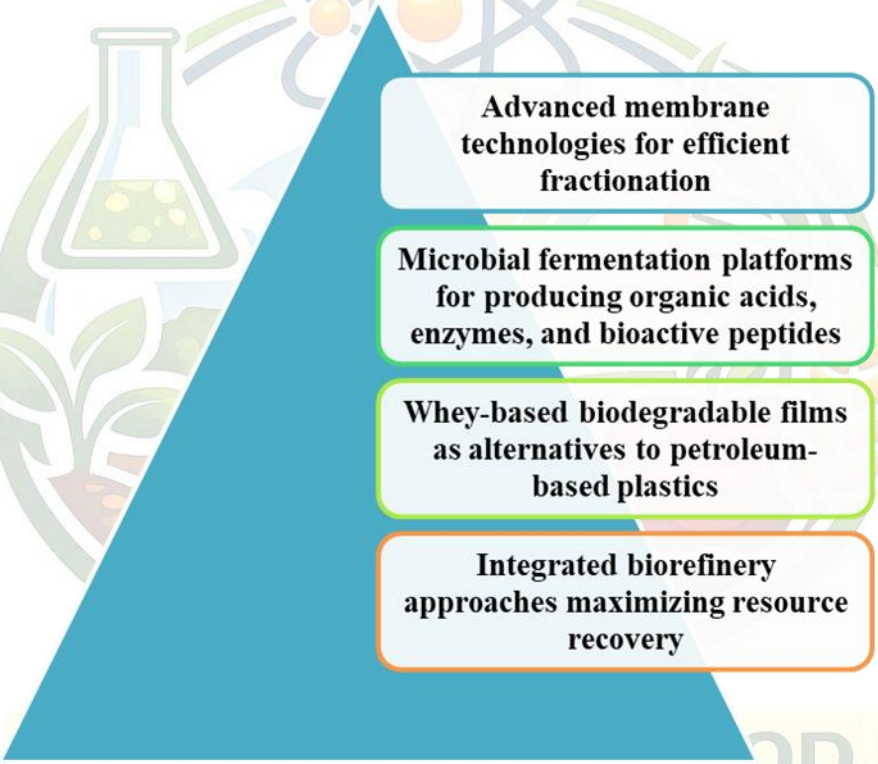


Fig.1 Key Future Key Future Opportunities

Despite progress mentioned in Fig.1, challenges remain. Approximately 40–50% of global whey production remains underutilized, and high processing costs limit adoption by small- and medium-scale dairy operations, particularly in developing countries (Sar et al., 2022). Addressing these challenges requires continued innovation, supportive policies, and infrastructure investment. As global demand for sustainable protein sources rises, whey-derived products are well-positioned to meet nutritional needs while contributing to environmental protection and sustainable development goals (Fortune Business Insights, 2026; Peeling et al., 2019).

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Demonstration of New High Yielding Groundnut Variety GG-34 Under Frontline Demonstrations (FLD's): Success Story

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Amit Tomar[1]

[1]Subject Matter Specialist (Plant Breeding), ICAR-Krishi Vigyan Kendra, Gajraula (Amroha), Sardar Vallabhbhai Patel University of Agriculture & Technology, Meerut.

Details of the Demonstrations

Name of KVK	KVK Amroha
Name of crop	Groundnut
Name of variety	GG-34
Name of farmer	Shri Hukum Singh
Farmer Address	Sri Hukum Singh S/O: Shri Chatroo Singh Village : Toniya Mafi Block: Dhanaura District: Amroha
Background information about farmer field	Shri Hukum Singh ji of Amroha district after completion his education up to 8th class, engaged himself in agriculture in his own land for running his family. He possesses 01 ha of land, out of which he cultivates Cereal Crop in 2.00 ha and 1.00 ha under vegetable cultivation. But income generated from his farm was not enough for smooth running of his family. Later on he formed a farmers group along with few youths.
Details of technology demonstrated	• High yielding Oil Seed Crop Groundnut GG-34 • Seed inoculation with Biofertilizer • Vermicompost @ 2.5 q/ha • 50 % recommended dose of N and full dose of P, K, Sulphur fertilizer
Institutional Involvement	KVK Amroha has demonstrated the high yielding Groundnut variety GG-34 along with other technology mentioned above during Kharif, 2025 under CFLD on Oilseed Crop.
Success Point	They wanted to grow Oil Seed Crop were remain fallow during Kharif season. Shri Hukum Singh Ji along with his group came to KVK Amroha and they expressed their willingness to utilize that area for crop production. Then a team of scientists from KVK, Amroha visited the area and after discussion with the farmers and necessary survey, conducted a training program for them. Later on, they were provided with seeds of high yielding Oil Seed Crop Groundnut variety GG-34 and other necessary inputs for demonstration. The crop was sown during July, 2025 and harvested during October, 2025. They have harvested a very good crop (Yield: 22.85 q/ha) and earned a very good income (Net income Rs. 86,399 /ha).
Farmers feedback	After successful implementation of the technology, farmers in the village were highly impressed and motivated by the performance of the new variety (Groundnut variety GG-34) of with improved cultivation practices due to its higher net income. He is now a role model not only in his village but also for the entire farming community of the nearby villages. Farmers from other villages are motivated by the success of this farmer and showing keen interest to implement pulses production program with proven HYV seeds in their villages. These interventions have the potential to create positive impact on Oil Seed production in Amroha district which will benefit the farmers at large.
Outcome yield	**22.85 q/ha**
Potential yield of variety	37 q/ha (Average pod yield) and 25 q/ha (Average kernel yield)
District average	15-20 q/ha
State average	20-25 q/ha

Performance of Technology Vis-À-Vis Local Check (Increase in Productivity and Returns)

Specific Technology	Yield (q/ha)	Gross cost (Rs/ha)	Gross income (Rs/ha)	Net income (Rs/ha	B:C ratio
Farmer practices	17.45	75,890	1,26,740	50,850	**1.67**
Demonstration	22.85	79,560	1,65,959	86,399	**2.08**

% Increase	23.63	-	-	-	-

Photographs of Technology Demonstrated at Farmers Field



Demostraion Plot of Groundnut variety GG-34 at farmers field during Kharif, 2025

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Demonstration of New High Yielding Mustard Variety RH-0761 Under Cluster Frontline Demonstrations (CFLD's): Success story

Article ID: 73618

Amit Tomar[1]

[1]Subject Matter Specialist (Plant Breeding), ICAR-Krishi Vigyan Kendra, Gajraula (Amroha), Sardar Vallabhbhai Patel University of Agriculture & Technology, Meerut.

Details of the Demonstrations

Name of KVK	KVK Amroha
Name of crop	Mustard
Name of variety	RH-761
Name of farmer	Shri Sompal Singh
Farmer Address	Sri Sompal Singh S/O: Shri Nathu Singh Village : Varshabad Block: Gajraula District: Amroha
Background information about farmer field	Shri Sompal Singh ji of Amroha district after completion his education up to 8th class, engaged himself in agriculture in his own land for running his family. He possesses 03 ha of land, out of which he cultivates Cereal Crop in 2.00 ha and 1.00 ha under vegetable cultivation. But income generated from his farm was not enough for smooth running of his family. Later on he formed a farmers group along with few youths.
Details of technology demonstrated	• High yielding Oil Seed Crop Mustard RH-761 • Seed inoculation with Biofertilizer • Vermicompost @ 2.5 q/ha • 50 % recommended dose of N and full dose of P, K, Sulphur fertilizer
Institutional Involvement	KVK Amroha has demonstrated the high yielding Mustard variety RH-761 along with other technology mentioned above during Rabi, 2025-26 under CFLD on Oilseed Crop.
Success Point	They wanted to grow Oil Seed Crop were remain fallow during Rabi season. Shri Sompal Singh Ji along with his group came to KVK Amroha and they expressed their willingness to utilize that area for crop production. Then a team of scientists from KVK, Amroha visited the area and after discussion with the farmers and necessary survey, conducted a training program for them. Later on, they were provided with seeds of high yielding Oil Seed Crop Mustard variety RH-761 and other necessary inputs for demonstration. The crop was sown during September, 2025 and harvested during February, 2025-26. They have harvested a very good crop (Yield: 21.36 q/ha) and earned a very good income (Net income Rs. 1,06,922 /ha).
Farmers feedback	After successful implementation of the technology, farmers in the village were highly impressed and motivated by the performance of the new variety (Mustard variety RH-761) of with improved cultivation practices due to its higher net income. He is now a role model not only in his village but also for the entire farming community of the nearby villages. Farmers from other villages are motivated by the success of this farmer and showing keen interest to implement pulses production program with proven HYV seeds in their villages. These interventions have the potential to create positive impact on Oil Seed production in Amroha district which will benefit the farmers at large.
Outcome yield	**21.36 q/ha**
Potential yield of variety	25-27 q/ha
District average	16-18 q/ha (District Amroha)
State average	12-13 q/ha

Performance of Technology Vis-À-Vis Local Check (Increase in Productivity and Returns)

Specific Technology	Yield (q/ha)	Gross cost (Rs/ha)	Gross income (Rs/ha)	Net income (Rs/ha	B:C ratio
Farmer practices	15.49	24,490	96,038	44,548	1.81
Demonstration	21.36	25,510	1,32,432	1,06,922	4.19

% Increase	27.48	-	-	-	-

Photographs of Technology Demonstrated at Farmers Field



Demonstration Plot of Mustard variety RH-761 at farmers field during Rabi, 2025-26

Photographs of Technology Demonstrated at Farmers Field



Organized one day training program on "New high yielding varieties of Mustard and their quality seed production technology under Cluster Frontline Demonstrations (CFLD's) on Oilseeds (Mustard) variety RH-0761 Krishi Vigyan Kendra, Gajraula, Amroha during 16th March, 2026.





Organized one day training program on "New high yielding varieties of Mustard and their quality seed production technology under Cluster Frontline Demonstrations (CFLD's) on Oilseeds (Mustard) variety RH-0761 Krishi Vigyan Kendra, Gajraula, Amroha during 17th March, 2026. List of trainings.

Details of Farmers Training Program Under CFLD Oilseed During 2025-26

S.No.	Date	Training topics	Total no. of participants
1.	18.03.2026	New high yielding varieties of Oilseed crops, Integrated Nutrient Management (INM), Integrated Pest Management (IPM) and quality seed production technology.	50
2.	17.03.2026	New high yielding varieties of Oilseed crops, Integrated Nutrient Management (INM), Integrated Pest Management (IPM) and quality seed production technology.	50
3.	16.03.2026	New high yielding varieties of Oilseed crops, Integrated Nutrient Management (INM), Integrated Pest Management (IPM) and quality seed production technology.	50

Details of Field Day Organized at Farmers Field Under CFLD Oilseed Program During 2025-26

S.No.	Date	Training topics	Total no. of participants
1.	20.12.2026	New high yielding varieties of Mustard and their production technology.	20
2.	22.12.2026	New high yielding varieties of Mustard and their production technology.	20
3.	10.03.2026	New high yielding varieties of Mustard and their production technology.	20
4.	19.03.2026	New high yielding varieties of Mustard and their production technology.	20

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Demonstration of New High Yielding Sesame Variety GT-06 Under Cluster Frontline Demonstrations (CFLD's): Success Story

Article ID: 73619

Amit Tomar[1]

[1]Subject Matter Specialist (Plant Breeding), ICAR-Krishi Vigyan Kendra, Gajraula (Amroha), Sardar Vallabhbhai Patel University of Agriculture & Technology, Meerut.

Details of the Demonstrations

Name of KVK	KVK Amroha
Name of crop	Sesame
Name of variety	GT-06
Name of farmer	Shri Chandrapal Singh
Farmer Address	Sri Chandrpall Singh S/O: Shri Guru Sahay Singh Village : Fatehpur Shumali Block: Gajraula District: Amroha
Background information about farmer field	Shri Chandrapal Singh ji of Amroha district after completion his education up to 10th class, engaged himself in agriculture in his own land for running his family. He possesses 02 ha of land, out of which he cultivates Cereal Crop in 1.00 ha and 1.00 ha under vegetable cultivation. But income generated from his farm was not enough for smooth running of his family. Later on he formed a farmers group along with few youths.
Details of technology demonstrated	• High yielding Oil Seed Crop Sesame GT-06 • Seed inoculation with Biofertilizer • Vermicompost @ 2.5 q/ha • 50 % recommended dose of N and full dose of P, K, Sulphur fertilizer
Institutional Involvement	KVK Amroha has demonstrated the high yielding Sesame variety GT-06 along with other technology mentioned above during Kharif, 2025 under CFLD on Oilseed Crop.
Success Point	They wanted to grow Oil Seed Crop were remain fallow during Kharif season. Shri Chandrapal Singh Ji along with his group came to KVK Amroha and they expressed their willingness to utilize that area for crop production. Then a team of scientists from KVK, Amroha visited the area and after discussion with the farmers and necessary survey, conducted a training program for them. Later on, they were provided with seeds of high yielding Oil Seed Crop Sesame variety GT-06 and other necessary inputs for demonstration. The crop was sown during July, 2025 and harvested during October, 2025-26. They have harvested a very good crop (Yield: 10.56 q/ha) and earned a very good income (Net income Rs. 78,079 /ha).
Farmers feedback	After successful implementation of the technology, farmers in the village were highly impressed and motivated by the performance of the new variety (Sesame variety GT-06) of with improved cultivation practices due to its higher net income. He is now a role model not only in his village but also for the entire farming community of the nearby villages. Farmers from other villages are motivated by the success of this farmer and showing keen interest to implement pulses production program with proven HYV seeds in their villages. These interventions have the potential to create positive impact on Oil Seed production in Amroha district which will benefit the farmers at large.
Outcome yield	10.56 q/ha
Potential yield of variety	06-07 q/ha
District average	7.50 q/ha
State average	08-12 q/ha

Performance of Technology Vis-À-Vis Local Check (Increase in Productivity and Returns)

Specific Technology	Yield (q/ha)	Gross cost (Rs/ha)	Gross income (Rs/ha)	Net income (Rs/ha	B:C ratio
Farmer practices	7.95	28,920	78,275	49,355	**2.70**
Demonstration	10.56	25,895	1,03,974	78,079	**4.02**

% Increase	24.72	-	-	-	-

Photographs of Technology Demonstrated at Farmers Field



Demonstration Plot of Sesame variety GT-06 at farmers field during Kharif, 2025

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Demonstration of New High Yielding Basmati Rice Variety Pusa Basmati-1847 Under Frontline Demonstrations (FLD's): Success Story

Article ID: 73620

Amit Tomar[1]

[1]Subject Matter Specialist (Plant Breeding), ICAR-Krishi Vigyan Kendra, Gajraula (Amroha), Sardar Vallabhbhai Patel University of Agriculture & Technology, Meerut.

Details of the Demonstrations

Name of KVK	KVK Amroha
Name of crop	Basmati Rice
Name of variety	Pusa Basmati-1847
Name of farmer	Shri Jaiveer Singh
Farmer Address	Sri Jaiveer Singh S/O: Shri Shiv Dhayan Singh Village : Kumrala Block: Gajraula District: Amroha
Background information about farmer field	Shri Jaiveer Singh ji of Amroha district after completion his education up to 10th class, engaged himself in agriculture in his own land for running his family. He possesses 03 ha of land, out of which he cultivates Cereal Crop in 2.00 ha and 1.00 ha under vegetable cultivation. But income generated from his farm was not enough for smooth running of his family. Later on he formed a farmers group along with few youths.
Details of technology demonstrated	• High yielding Basmati rice Crop variety Pusa Basmati-1847 • Seed inoculation with Biofertilizer • Vermicompost @ 2.5 q/ha 50 % recommended dose of N and full dose of P, K, Sulphur fertilizer
Institutional Involvement	KVK Amroha has demonstrated the high yielding Basmati rice variety Pusa Basmati-1847 along with other technology mentioned above during Kharif, 2025 under FLD program.
Success Point	They wanted to grow Basmati rice Crop were remain fallow during Kharif season. Shri Jaiveer Singh Ji along with his group came to KVK Amroha and they expressed their willingness to utilize that area for crop production. Then a team of scientists from KVK, Amroha visited the area and after discussion with the farmers and necessary survey, conducted a training program for them. Later on, they were provided with seeds of high yielding Basmati rice crop variety Pusa Basmati and other necessary inputs for demonstration. The crop was sown during July, 2025 and harvested during October, 2025. They have harvested a very good crop (Yield: 47.25 q/ha) and earned a very good income (Net income Rs. 76,230 /ha).
Farmers feedback	After successful implementation of the technology, farmers in the village were highly impressed and motivated by the performance of the new variety (Basmati rice variety Pusa Basmati-1847) of with improved cultivation practices due to its higher net income. He is now a role model not only in his village but also for the entire farming community of the nearby villages. Farmers from other villages are motivated by the success of this farmer and showing keen interest to implement pulses production program with proven HYV seeds in their villages. These interventions have the potential to create positive impact on Basmati rice production in Amroha district which will benefit the farmers at large.

Performance of Technology Vis-À-Vis Local Check (Increase in Productivity and Returns)

Specific Technology	Yield (q/ha)	Gross cost (Rs/ha)	Gross income (Rs/ha)	Net income (Rs/ha	B:C ratio
Farmer practices	36.50	42,540	87,198	44,658	2.05
Demonstration	47.25	36,650	1,12,880	76,230	3.08
% Increase	22.75	-	-	-	-

Photographs of Technology Demonstrated at Farmers Field









Demonstration Plot of Basmati rice variety Pusa Basmati-1847 at farmers field during Kharif, 2025

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Demonstration of New High Yielding Basmati Rice Variety Pusa Basmati-1885 Under Frontline Demonstrations (FLD's): Success Story

Article ID: 73621

Amit Tomar[1]

[1]Subject Matter Specialist (Plant Breeding), ICAR-Krishi Vigyan Kendra, Gajraula (Amroha), Sardar Vallabhbhai Patel University of Agriculture & Technology, Meerut.

Details of the Demonstrations

Name of KVK	KVK Amroha
Name of crop	Basmati Rice
Name of variety	Pusa Basmati-1885
Name of farmer	Shri Kartar Singh
Farmer Address	Sri Kartar Singh S/O: Shri Pran Shukh Village : Kumrala Block: Gajraula District: Amroha
Background information about farmer field	Shri Kartar Singh ji of Amroha district after completion his education up to 12th class, engaged himself in agriculture in his own land for running his family. He possesses 2.5 ha of land, out of which he cultivates Cereal Crop in 2.00 ha and 0.50 ha under vegetable cultivation. But income generated from his farm was not enough for smooth running of his family. Later on he formed a farmers group along with few youths.
Details of technology demonstrated	• High yielding Basmati rice Crop variety Pusa Basmati-1885 • Seed inoculation with Biofertilizer • Vermicompost @ 2.5 q/ha 50 % recommended dose of N and full dose of P, K, Sulphur fertilizer
Institutional Involvement	KVK Amroha has demonstrated the high yielding Basmati rice variety Pusa Basmati-1885 along with other technology mentioned above during Kharif, 2025 under FLD program.
Success Point	They wanted to grow Basmati rice Crop were remain fallow during Kharif season. Shri Kartar Singh Ji along with his group came to KVK Amroha and they expressed their willingness to utilize that area for crop production. Then a team of scientists from KVK, Amroha visited the area and after discussion with the farmers and necessary survey, conducted a training program for them. Later on, they were provided with seeds of high yielding Basmati rice crop variety Pusa Basmati and other necessary inputs for demonstration. The crop was sown during July, 2025 and harvested during October, 2025. They have harvested a very good crop (Yield 45.85: q/ha) and earned a very good income (Net income Rs. 73,886 /ha).
Farmers feedback	After successful implementation of the technology, farmers in the village were highly impressed and motivated by the performance of the new variety (Basmati rice variety Pusa Basmati-1885) of with improved cultivation practices due to its higher net income. He is now a role model not only in his village but also for the entire farming community of the nearby villages. Farmers from other villages are motivated by the success of this farmer and showing keen interest to implement pulses production program with proven HYV seeds in their villages. These interventions have the potential to create positive impact on Basmati rice production in Amroha district which will benefit the farmers at large.

Performance of Technology Vis-À-Vis Local Check (Increase in Productivity and Returns)

Specific Technology	Yield (q/ha)	Gross cost (Rs/ha)	Gross income (Rs/ha)	Net income (Rs/ha	B:C ratio
Farmer practices	36.50	42,540	87,198	44,658	2.0
Demonstration	45.85	35,650	1,09,536	73,886	3.07
% Increase	20.39	-	-	-	-

Photographs of Technology Demonstrated at Farmers Field



Demonstration Plot of Basmati rice variety Pusa Basmati-1885 at farmers field during Kharif, 2025

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Demonstration of New High Yielding Timely Sown Wheat Variety HD-3385 Under Frontline Demonstrations (FLD's): Success Story

Article ID: 73622

Amit Tomar[1]

[1]Subject Matter Specialist (Plant Breeding), ICAR-Krishi Vigyan Kendra, Gajraula (Amroha), Sardar Vallabhbhai Patel University of Agriculture & Technology, Meerut.

Details of the Demonstrations

Name of KVK	KVK Amroha
Name of crop	Wheat
Name of variety	HD-3385
Name of farmer	Shri Ankit Kumar
Farmer Address	Shri Ankit Kumar S/O: Shri Sompal Singh Village : Varshabad Block: Gajraula District: Amroha
Background information about farmer field	Shri Ankit Kumar ji of Amroha district after completion his education up to Graduations degree, engaged himself in agriculture in his own land for running his family. He possesses 03 ha of land, out of which he cultivates Cereal Crop in 2.00 ha and 1.00 ha under vegetable cultivation. But income generated from his farm was not enough for smooth running of his family. Later on he formed a farmers group along with few youths.
Details of technology demonstrated	• High yielding Wheat Crop variety HD-3385 • Seed inoculation with Biofertilizer • Vermicompost @ 2.5 q/ha 50 % recommended dose of N and full dose of P, K, Sulphur fertilizer
Institutional Involvement	KVK Amroha has demonstrated the high yielding Wheat variety HD-3385 along with other technology mentioned above during Rabi, 2025-26 under FLD program.
Success Point	They wanted to grow Wheat Crop were remain fallow during rabi season. Shri Ankit Kumar Ji along with his group came to KVK Amroha and they expressed their willingness to utilize that area for crop production. Then a team of scientists from KVK, Amroha visited the area and after discussion with the farmers and necessary survey, conducted a training program for them. Later on, they were provided with seeds of high yielding Wheat crop variety HD-3385 and other necessary inputs for demonstration. The crop was sown during November, 2025 and harvested during April, 2026. They have harvested a very good crop (Yield: 68.00 q/ha) and earned a very good income (Net income Rs. 1,28,880 /ha).
Farmers feedback	After successful implementation of the technology, farmers in the village were highly impressed and motivated by the performance of the new variety (Wheat variety HD-3385) of with improved cultivation practices due to its higher net income. He is now a role model not only in his village but also for the entire farming community of the nearby villages. Farmers from other villages are motivated by the success of this farmer and showing keen interest to implement pulses production program with proven HYV seeds in their villages. These interventions have the potential to create positive impact on Basmati rice production in Amroha district which will benefit the farmers at large.

Performance of Technology Vis-À-Vis Local Check (Increase in Productivity and Returns)

Specific Technology	Yield (q/ha)	Gross cost (Rs/ha)	Gross income (Rs/ha)	Net income (Rs/ha	B:C ratio
Farmer practices	48.32	45,500	1,24,907	79,407	1.74
Demonstration	68.00	96,900	1,75,780	1,28,880	2.74
% Increase	28.94	-	-	-	-

Photographs of Technology Demonstrated at Farmers Field





Demonstration Plot of Wheat variety HD-3385 at farmers field during Rabi, 2025-26

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Demonstration of New High Yielding Late Sown Wheat Variety PBW-226 Under Frontline Demonstrations (FLD's): Success Story

Article ID: 73623

Amit Tomar[1]

[1]Subject Matter Specialist (Plant Breeding), ICAR-Krishi Vigyan Kendra, Gajraula (Amroha), Sardar Vallabhbhai Patel University of Agriculture & Technology, Meerut.

Details of the Demonstrations

Name of KVK	KVK Amroha
Name of crop	Wheat
Name of variety	PBW-226
Name of farmer	Shri Brijpal Singh
Farmer Address	Shri Brijpal Singh S/O: Shri Kale Singh Village : Dhanauri Mafi Block: Gajraula District: Amroha
Background information about farmer field	Shri Brijpal Singh ji of Amroha district after completion his education up to Graduations degree, engaged himself in agriculture in his own land for running his family. He possesses 02 ha of land, out of which he cultivates Cereal Crop in 1.00 ha and 1.00 ha under vegetable cultivation. But income generated from his farm was not enough for smooth running of his family. Later on he formed a farmers group along with few youths.
Details of technology demonstrated	• High yielding Wheat Crop variety PBW-226 • Seed inoculation with Biofertilizer • Vermicompost @ 2.5 q/ha 50 % recommended dose of N and full dose of P, K, Sulphur fertilizer
Institutional Involvement	KVK Amroha has demonstrated the high yielding Wheat variety PBW-226 along with other technology mentioned above during Rabi, 2025-26 under FLD program.
Success Point	They wanted to grow Wheat Crop were remain fallow during rabi season. Shri Brijpal Singh Ji along with his group came to KVK Amroha and they expressed their willingness to utilize that area for crop production. Then a team of scientists from KVK, Amroha visited the area and after discussion with the farmers and necessary survey, conducted a training program for them. Later on, they were provided with seeds of high yielding Wheat crop variety PBW-226 and other necessary inputs for demonstration. The crop was sown during December, 2025 and harvested during April, 2026. They have harvested a very good crop (Yield: 55.00 q/ha) and earned a very good income (Net income Rs. 95,275 /ha).
Farmers feedback	After successful implementation of the technology, farmers in the village were highly impressed and motivated by the performance of the new variety (Late sown Wheat variety PBW-226) of with improved cultivation practices due to its higher net income. He is now a role model not only in his village but also for the entire farming community of the nearby villages. Farmers from other villages are motivated by the success of this farmer and showing keen interest to implement pulses production program with proven HYV seeds in their villages. These interventions have the potential to create positive impact on Basmati rice production in Amroha district which will benefit the farmers at large.

Performance of Technology Vis-À-Vis Local Check (Increase in Productivity and Returns)

Specific Technology	Yield (q/ha)	Gross cost (Rs/ha)	Gross income (Rs/ha)	Net income (Rs/ha	B:C ratio
Farmer practices	40.25	45,500	1,04,046	58,546	1.28
Demonstration	55.00	46,900	1,42,175	95,275	2.03
% Increase	26.81	-	-	-	-

Photographs of Technology Demonstrated at Farmers Field





Demonstration Plot of Late sown Wheat variety PBW-226 at farmers field during Rabi, 2025-26

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Demonstration of New High Yielding Late Sown Wheat Variety PBW-752 Under on Farm Trials (OFT's): Success Story

Article ID: 73624

Amit Tomar[1]

[1]Subject Matter Specialist (Plant Breeding), ICAR-Krishi Vigyan Kendra, Gajraula (Amroha), Sardar Vallabhbhai Patel University of Agriculture & Technology, Meerut.

Details of the Demonstrations

Name of KVK	KVK Amroha
Name of crop	Wheat
Name of variety	PBW-752
Name of farmer	Shri Sher Singh
Farmer Address	Shri Sher Singh S/O: Shri Ram Gopal Singh Village: Toniya Mafi Block: Dhanaura District: Amroha
Background information about farmer field	Shri Sher Singh ji of Amroha district after completion his education up to Graduations degree, engaged himself in agriculture in his own land for running his family. He possesses 02 ha of land, out of which he cultivates Cereal Crop in 1.00 ha and 1.00 ha under vegetable cultivation. But income generated from his farm was not enough for smooth running of his family. Later on he formed a farmers group along with few youths.
Details of technology demonstrated	• High yielding Wheat Crop variety PBW-752 • Seed inoculation with Biofertilizer • Vermicompost @ 2.5 q/ha 50 % recommended dose of N and full dose of P, K, Sulphur fertilizer
Institutional Involvement	KVK Amroha has demonstrated the high yielding Wheat variety PBW-752 along with other technology mentioned above during Rabi, 2025-26 under FLD program.
Success Point	They wanted to grow Wheat Crop were remain fallow during rabi season. Shri Sher Singh Ji along with his group came to KVK Amroha and they expressed their willingness to utilize that area for crop production. Then a team of scientists from KVK, Amroha visited the area and after discussion with the farmers and necessary survey, conducted a training program for them. Later on, they were provided with seeds of high yielding Wheat crop variety PBW-752 and other necessary inputs for demonstration. The crop was sown during December, 2025 and harvested during April, 2026. They have harvested a very good crop (Yield: 55.36 q/ha) and earned a very good income (Net income Rs. 96,206 /ha).
Farmers feedback	After successful implementation of the technology, farmers in the village were highly impressed and motivated by the performance of the new variety (Late sown Wheat variety PBW-752) of with improved cultivation practices due to its higher net income. He is now a role model not only in his village but also for the entire farming community of the nearby villages. Farmers from other villages are motivated by the success of this farmer and showing keen interest to implement pulses production program with proven HYV seeds in their villages. These interventions have the potential to create positive impact on Basmati rice production in Amroha district which will benefit the farmers at large.

Performance of Technology Vis-À-Vis Local Check (Increase in Productivity and Returns)

Specific Technology	Yield (q/ha)	Gross cost (Rs/ha)	Gross income (Rs/ha)	Net income (Rs/ha	B:C ratio
Farmer practices	40.35	45,500	1,04,304	58,804	1.28
Demonstration	55.36	46,900	1,43,106	96,206	2.05
% Increase	27.12	-	-	-	-

Photographs of Technology Demonstrated at Farmers Field



Demonstration Plot of Late sown Wheat variety PBW-752 at farmers field during Rabi, 2025-26

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Decoding Diversity: How Pan Genomes are Transforming Crop Science

Article ID: 73625

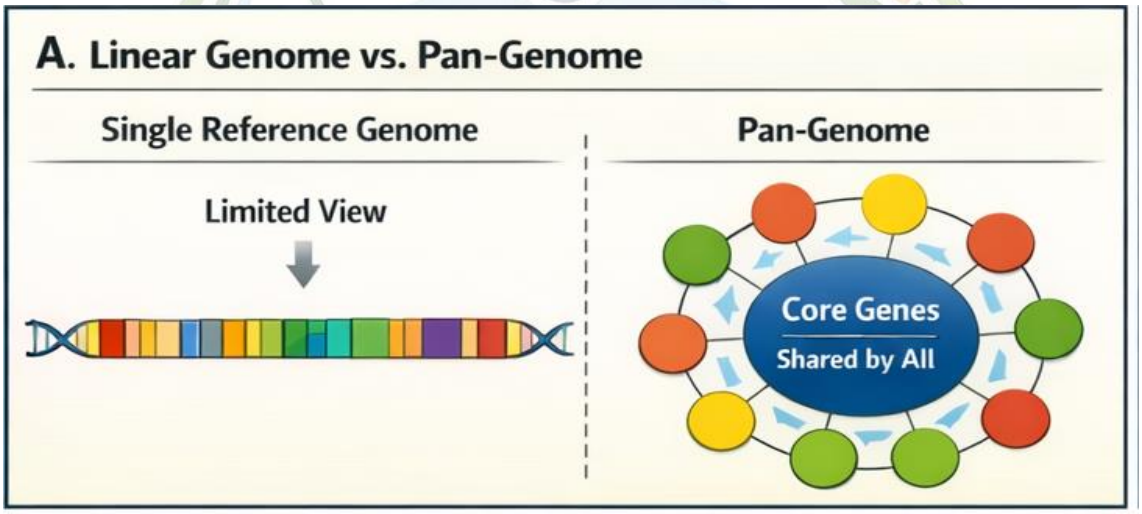
Bokka Kiranmayee[1], Naresh Kumar Sahu[1]
[1]Department of Genetics and Plant Breeding, College of Agriculture, Indira Gandhi Krishi Vishwavidyalya, Raipur, Chhattisgarh, India.

Introduction

For many years, plant genetics research has relied on a single "reference genome" to represent the complete DNA sequence of a species. While this approach has been instrumental in advancing genomic studies, it provides only a partial view of the genetic complexity inherent within plant populations.

A single reference genome cannot adequately capture the extensive variation present across diverse cultivars, landraces, and wild relatives. As a result, significant portions of genetic diversity particularly genes associated with important agronomic traits such as drought tolerance, disease resistance, and quality attributes have remained undetected. These genes are often absent from the reference genome but present in other individuals, leading to gaps in our understanding of functional variation.

To overcome these limitations, plant geneticists have adopted the concept of the pan-genome. A pan-genome represents the full complement of genes within a species, encompassing both core genes shared by all individuals and variable or accessory genes that differ among them. This comprehensive framework provides a more complete and accurate representation of genomic diversity, thereby offering new opportunities for crop improvement and advancing sustainable agriculture.

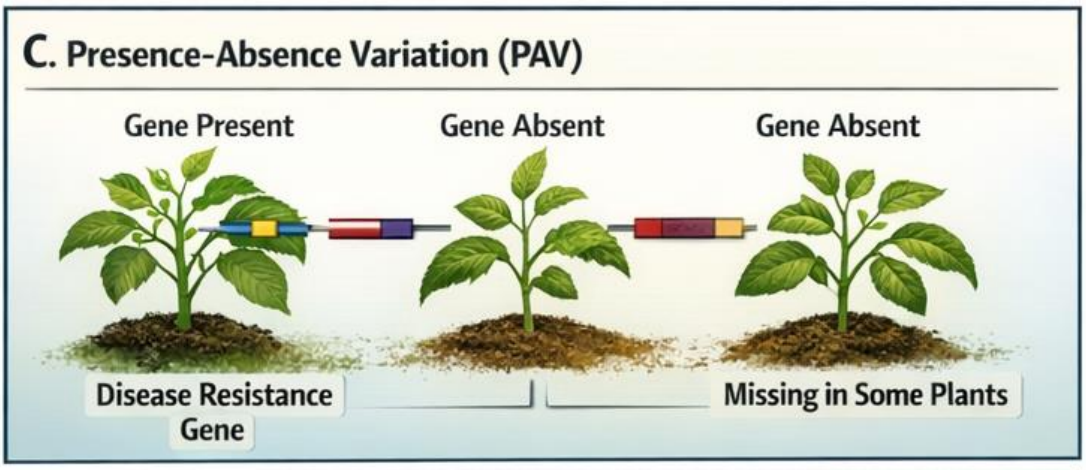


The Comprehensive Genetic Landscape

The term pan-genome is derived from the Greek word "pan," meaning "all," reflecting its objective of capturing the complete genetic repertoire of a species. Rather than relying on a single reference, this framework integrates genomic information from multiple individuals to provide a comprehensive and inclusive representation of genetic diversity. Conceptually, a plant pan-genome is divided into two major components:

Core Genome: This comprises genes that are conserved across all individuals within a species. These genes are typically evolutionarily stable, exhibit low mutation rates, and are essential for fundamental biological and cellular functions. They form the basic genetic framework necessary for survival and development.

Accessory (Variable) Genome: This component includes genes that are present only in certain individuals, populations, or varieties. These genes are more dynamic and contribute to phenotypic diversity, adaptation to environmental conditions, and important agronomic traits such as stress tolerance, disease resistance, and yield variability. Although the concept of the pan-genome was first introduced in bacterial systems in 2005 and later extended to plants in 2007, significant progress in sequencing technologies led to rapid advancements in the field around 2014. Landmark studies in crops such as soybean, rice, and maize demonstrated the feasibility and value of constructing pan-genomes, highlighting their importance for understanding complex genomic variation.



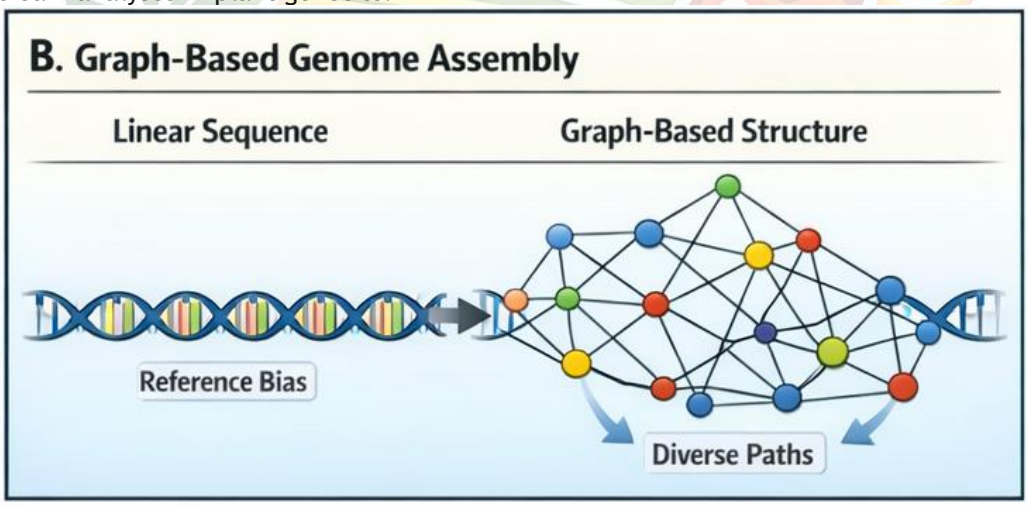
Advancing Genome Assembly: From Linear Models to Graph-Based Frameworks

Constructing pan genomes represents a significant computational and methodological challenge. Early genome assembly approaches, such as iterative assembly and reference based methods, relied on aligning newly sequenced DNA fragments to a single linear reference genome. While effective for basic comparisons, these approaches inherently introduced reference bias, limiting the detection of complex genomic variations.

Linear models tend to oversimplify genomic diversity, often failing to capture structural variations and presence absence variations (PAVs) genes that may be entirely missing in some individuals but present in others. As a result, substantial portions of biologically meaningful variation remained unresolved.

To address these limitations, graph-based genome assembly has emerged as the current standard. In this framework, genomes are represented as interconnected networks rather than single linear sequences. Genetic variants are incorporated as alternative paths within the graph, allowing multiple genomic configurations to coexist within a unified structure. This approach enables a more accurate and unbiased representation of genetic diversity across individuals.

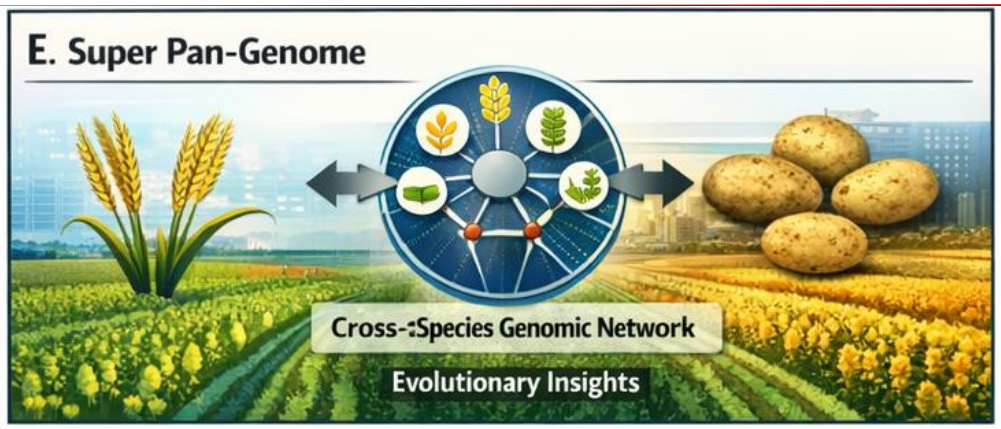
Although graph-based methods demand substantial computational resources, large-scale data storage, and advanced long-read sequencing technologies, they provide a robust foundation for capturing complex genomic architecture and improving downstream analyses in plant genetics.



Toward Data-Driven Agriculture: The Role of Artificial Intelligence

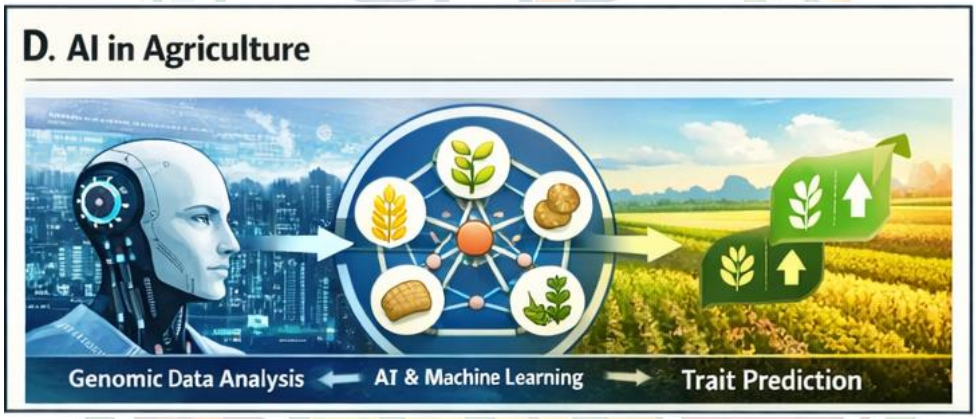
The rapid expansion of pan-genomic datasets is driving a transition toward data-intensive and predictive approaches in agriculture. The integration of artificial intelligence (AI) and machine learning is increasingly critical for managing and interpreting the vast and complex datasets generated through pan genome studies.

Several challenges remain, particularly in crops with complex genomes. Species such as potato exhibit polyploidy and high levels of heterozygosity, complicating genome assembly and analysis. Despite these challenges, recent efforts have extended beyond species-level pan-genomes to develop super-pan-genomes, which integrate genomic information across related species or entire genera. These expanded frameworks enable deeper insights into evolutionary processes, gene flow, and interspecific variation.



Looking ahead, AI-driven models are expected to play a central role in decoding pan-genomic data. By integrating genomic and epigenomic information, these models can predict how specific genetic variations influence traits such as growth, yield, and stress tolerance. This predictive capacity has the potential to significantly accelerate crop improvement programs.

By shifting from single reference genomes to comprehensive pan-genomic frameworks, plant science is moving toward more precise and efficient breeding strategies. This transition is expected to reduce crop development timelines and enhance the ability to develop resilient varieties, particularly in the context of climate variability and increasing global food demand.



Applications in Crop Improvement and Evolutionary Studies

The practical applications of pan-genomics are increasingly influencing both crop improvement strategies and our understanding of plant evolution.

Enhancing Crop Quality Traits: Pan-genome analyses in tomato have revealed numerous previously undetected genes associated with flavor. One notable example is the allele TomLoxC, which plays a key role in regulating flavor intensity. This allele was largely lost during conventional breeding focused on yield, shelf life, and transportability. Its identification has enabled the development of molecular markers, facilitating the reintroduction of improved flavor traits into modern cultivars.

Understanding Crop Origins and Evolution: Pan-genomic studies in apple have provided valuable insights into its domestication history. Evidence indicates that a substantial proportion of genes in cultivated apple varieties are derived from wild progenitors, particularly Malus sylvestris and Malus sieversii. These findings support the historical movement and domestication of apple across regions, contributing to a clearer understanding of its evolutionary trajectory.

Restoration of Lost Genetic Diversity: Domestication and selective breeding have often resulted in reduced genetic diversity, leading to the loss of beneficial traits. Pan genomes enable the identification of such lost or underutilized genes from wild relatives. These genes are now being reintroduced into elite cultivars to enhance traits such as broad-spectrum disease resistance in rice and improved protein content in soybean, thereby strengthening crop resilience and nutritional quality.

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Role of Natural Enemies in Insect-Pest Management of Crops

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Dr.Punam Madavi[1], Shri. A. N. Surpam[2], Nicky Bansod[3], Dr.V. D. Tayade[4]

[1]Assistant Professor (C) of Agril. Entomology, Bhausaheb Fundkar Government College of Agriculture, Buldhana, Maharashtra.

[2]Junior Research Assistant, Bhausaheb Fundkar Government College of Agriculture, Buldhana (Dr. PDKV., Akola), Maharashtra.

[3]Assistant Professor of Agril. Entomology, SVGI, College of Agriculture, Jalgaon, Jamod, Maharashtra.

[4]Assistant Professor (C) of Horticulture, Bhausaheb Fundkar Government College of Agriculture, Buldhana, Maharashtra.

Abstract

Natural enemies constitute a fundamental pillar of ecological pest regulation and sustainable crop protection. They include predators, parasitoids, and entomopathogens that naturally suppress insect pest populations through diverse biological interactions. Their integration into agricultural systems reduces reliance on synthetic pesticides, mitigates environmental risks, and enhances agroecosystem resilience. This review provides an in-depth analysis of the diversity, ecological roles, mechanisms, and applications of natural enemies in insect-pest management. It further examines their integration into Integrated Pest Management (IPM), habitat manipulation strategies, ecological intensification, and emerging innovations. The constraints and future research directions for optimizing biological control are also critically discussed, highlighting the need for interdisciplinary approaches to achieve sustainable agriculture.

Introduction

Insect pests are responsible for substantial quantitative and qualitative losses in agricultural production worldwide, often reducing yields by 20–40% under unmanaged conditions. Historically, pest control has relied heavily on synthetic chemical pesticides; however, their indiscriminate use has led to severe consequences, including pesticide resistance, resurgence of secondary pests, environmental contamination, and adverse effects on non-target organisms, including beneficial insects and human health.

In response to these challenges, biological control using natural enemies has gained prominence as a viable and eco-friendly alternative. Natural enemies regulate pest populations through trophic interactions and form the backbone of ecologically based pest management strategies. Their role is particularly emphasized in Integrated Pest Management (IPM), where they contribute to maintaining pest populations below economic threshold levels while minimizing environmental impacts.

The concept of utilizing natural enemies aligns with the principles of agroecology and ecological intensification, where biodiversity and ecosystem services are harnessed to improve agricultural sustainability. This review aims to provide a comprehensive understanding of the role of natural enemies in insect-pest management, encompassing their classification, ecological functions, practical applications, and future prospects.

Diversity and Classification of Natural Enemies

Natural enemies are broadly categorized into predators, parasitoids, and entomopathogens, each exhibiting distinct biological characteristics and modes of action.

Predators are typically generalists that consume multiple prey individuals during their lifetime. They include insects such as coccinellids (ladybird beetles), syrphid flies, lacewings, and predatory bugs, as well as non-insect organisms like spiders and predatory mites. Predators play a crucial role in suppressing populations of aphids, whiteflies, thrips, and other soft-bodied pests. Their effectiveness is often determined by their searching ability, feeding rate, and adaptability to environmental conditions.

Parasitoids are highly specialized organisms, predominantly belonging to the orders Hymenoptera and Diptera. Unlike predators, parasitoids require a single host to complete their development, ultimately leading to host death. They exhibit remarkable host specificity, which enhances their efficiency and reduces non-target effects. Egg parasitoids such as *Trichogramma* spp., larval parasitoids like *Cotesia* spp., and pupal parasitoids such as *Pteromalus* spp. are widely used in biological control programs.

Entomopathogens include microorganisms such as bacteria (*Bacillus thuringiensis*), fungi (*Beauveria bassiana*, *Metarhizium anisopliae*), viruses (nucleopolyhedroviruses), and nematodes (*Steinernema* and *Heterorhabditis* spp.). These organisms infect and kill insect hosts through complex physiological mechanisms, often leading to epizootics under favorable environmental conditions.

Mechanisms of Action and Ecological Dynamics

The effectiveness of natural enemies is governed by complex ecological interactions and biological mechanisms. Predators exert direct mortality through consumption and exhibit functional responses (change in feeding rate with prey density) and numerical responses (change in population size with prey availability). These responses are critical for stabilizing pest populations.

Parasitoids regulate host populations by reducing reproductive potential and increasing mortality. Their efficiency is influenced by host-searching behaviour, synchronization with host life cycles, and environmental conditions. Koinobiont parasitoids allow hosts to continue development after parasitism, while idiobiont parasitoids arrest host development immediately.

Entomopathogens infect hosts through ingestion, cuticular penetration, or direct contact. Once inside the host, they proliferate and disrupt physiological processes, eventually causing death. Environmental factors such as humidity, temperature, and UV radiation significantly influence their effectiveness. The interactions between natural enemies and pests are often density-dependent, ensuring that pest populations are kept below damaging levels. However, these interactions are also influenced by intraguild predation, competition, and resource availability.

Biological Control Approaches

Biological control using natural enemies is implemented through three primary approaches: classical, augmentative, and conservation biological control.

Classical biological control involves the introduction of natural enemies from the pest's native range to control invasive species. This approach has achieved notable success, such as the control of cottony cushion scale by *Rodolia cardinalis*. However, it requires rigorous risk assessment to prevent unintended ecological consequences.

Augmentative biological control involves the mass rearing and periodic release of natural enemies. Inoculative releases aim to establish populations for long-term control, while inundative releases provide immediate suppression. This approach is widely used in greenhouse crops and high-value horticultural systems.

Conservation biological control focuses on enhancing the effectiveness of existing natural enemies through habitat management, reduced pesticide use, and provision of supplementary resources. It is considered the most sustainable and cost-effective approach, as it leverages naturally occurring biodiversity.

Habitat Management and Ecological Engineering

Habitat manipulation plays a critical role in supporting natural enemy populations. Agricultural landscapes that incorporate ecological engineering practices, such as intercropping, crop rotation, and agroforestry, provide diverse habitats and resources for beneficial organisms. The establishment of flowering strips and cover crops enhances the availability of nectar and pollen, which are essential for adult parasitoids and predators. These resources improve longevity, fecundity, and overall effectiveness of natural enemies. Banker plant systems provide alternative hosts or prey, ensuring the persistence of natural enemies during periods of low pest abundance. Reduced tillage and maintenance of field margins contribute to habitat stability and refuge availability. Landscape-level diversity, including the presence of semi-natural habitats, facilitates the movement and colonization of natural enemies, thereby enhancing pest suppression.

Role in Integrated Pest Management (IPM)

Natural enemies are integral to IPM strategies, which aim to combine biological, cultural, mechanical, and chemical control methods. Their inclusion reduces reliance on chemical pesticides and promotes sustainable pest management. Monitoring and surveillance of pest and natural enemy populations are essential components of IPM. Decision-making is based on economic threshold levels, ensuring that interventions are applied only when necessary. Selective pesticides and biopesticides are preferred to minimize harm to beneficial organisms. Successful IPM programs incorporating natural enemies have been demonstrated in crops such as rice, cotton, vegetables, and fruit orchards. For instance, the use of parasitoids and predators in rice ecosystems has significantly reduced pest outbreaks and pesticide use.

Ecological Interactions and Multitrophic Relationships

Natural enemies operate within complex multitrophic systems involving plants, herbivores, and higher trophic levels. Plants play an active role in these interactions by producing volatile organic compounds (VOCs) in response to herbivore attack, which attract natural enemies. This phenomenon, known as indirect plant defence, enhances biological control. Intraguild predation, where natural enemies prey on each other, can influence the overall effectiveness of biological control. Similarly, competition among natural enemies for resources may affect their performance. Understanding these interactions is essential for optimizing pest management strategies. Climate change is expected to alter the distribution and effectiveness of natural enemies by influencing their phenology, survival, and interactions with pests. Adaptive management strategies will be required to address these challenges.

Advantages of Natural Enemies

The use of natural enemies offers numerous advantages over conventional pest control methods. They are environmentally benign and reduce pesticide residues in food and the environment. Their self-perpetuating nature ensures long-term pest suppression once established. Natural enemies contribute to biodiversity conservation and ecosystem stability. They are compatible with organic farming systems and reduce the risk of pest resistance. Economically, they lower input costs and enhance the sustainability of agricultural production systems.

Constraints and Challenges

Despite their potential, several constraints limit the widespread adoption of natural enemies. Environmental variability can affect their survival and performance. The specificity of some natural enemies may restrict their effectiveness against diverse pest complexes. Mass production and quality control of biological control agents require specialized infrastructure and expertise. Storage and transportation challenges further complicate their use. Additionally, the lack of awareness among farmers and limited extension services hinder adoption. The compatibility of natural enemies with chemical pesticides remains a critical issue. Non-selective pesticides can disrupt natural enemy populations and lead to pest resurgence.

Recent Advances and Innovations

Advances in molecular biology and biotechnology are enhancing the effectiveness of natural enemies. Genetic tools are being used to improve traits such as host-finding ability and environmental tolerance. Molecular markers facilitate accurate identification and monitoring of natural enemy populations. The use of semiochemicals, including pheromones and kairomones, is gaining attention for enhancing natural enemy attraction and efficiency. Artificial intelligence and remote sensing technologies are enabling precision pest monitoring and targeted deployment of biological control agents. Climate-resilient natural enemies are being developed to adapt to changing environmental conditions. Additionally, integration with digital agriculture platforms is improving decision-making and efficiency in pest management.

Future Perspectives

The future of natural enemy-based pest management lies in ecological intensification and the integration of advanced technologies. Research should focus on understanding multitrophic interactions, optimizing habitat management, and developing region-specific strategies. Policy support and institutional frameworks are essential for promoting the adoption of biological control. Capacity building, farmer education, and public awareness campaigns will play a crucial role in scaling up the use of natural enemies. The integration of natural enemies with other sustainable practices, such as biofertilizers and climate-smart agriculture, will contribute to resilient and productive agroecosystems.

Conclusion

Natural enemies are indispensable components of sustainable insect-pest management. Their ability to regulate pest populations, enhance biodiversity, and reduce dependence on chemical pesticides makes them a cornerstone of modern agriculture. While challenges remain, continued research, technological innovation, and policy support will enable the effective utilization of natural enemies in crop protection. Their integration into IPM systems represents a promising pathway toward achieving food security and environmental sustainability.

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Harnessing Indigenous Traditional Knowledge for Sustainable Agriculture Development in India

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Om Narayan Sharma[1]

[1]Department of Horticulture, Sam Higginbottom University of Agriculture, Technology & Sciences, Prayagraj, Uttar Pradesh.

Abstract

Indigenous Traditional Knowledge (ITK) represents a rich repository of location-specific, culturally embedded, and ecologically adaptive practices developed by farming communities over generations. In India, where agriculture is deeply intertwined with socio-cultural traditions and diverse agro-ecological conditions, ITK plays a pivotal role in ensuring sustainability, resilience, and food security. This review explores the multifaceted contributions of indigenous knowledge systems to sustainable agriculture, including soil fertility management, crop protection, biodiversity conservation, water management, and climate resilience. It also examines the integration of ITK with modern scientific approaches, challenges in its preservation, and policy interventions required for its effective utilization. The study emphasizes that revitalizing and mainstreaming ITK can significantly contribute to environmentally sound, economically viable, and socially inclusive agricultural development in India.

Introduction

Indian agriculture is a product of centuries of cumulative learning, adaptation, and innovation shaped by diverse agro-climatic conditions and socio-cultural traditions. Indigenous Traditional Knowledge, often referred to as Indigenous Technical Knowledge, forms the backbone of this long-standing agricultural heritage. It comprises a wide range of practices, beliefs, and innovations that have evolved through farmers' direct interaction with nature. Unlike modern agricultural technologies that are often input-intensive and generalized, ITK is inherently site-specific, resource-efficient, and ecologically harmonious. The advent of the Green Revolution brought significant gains in crop productivity but also introduced challenges such as soil degradation, declining water tables, loss of agro-biodiversity, and increased dependence on chemical inputs. These concerns have led to a paradigm shift toward sustainable agriculture, where indigenous knowledge systems are increasingly recognized as valuable assets. ITK offers a framework for developing resilient agricultural systems that are aligned with ecological processes and local resource availability.

Concept and Characteristics of Indigenous Traditional Knowledge

Indigenous Traditional Knowledge represents a cumulative body of wisdom developed by rural communities through continuous observation, experimentation, and adaptation to their environment. It is not static but evolves over time in response to ecological changes and socio-economic dynamics. This dynamic nature ensures that ITK remains relevant and adaptable to changing conditions.

One of the defining features of ITK is its location specificity, meaning that practices are tailored to local soil types, climatic conditions, and cultural contexts. This makes ITK highly effective in addressing region-specific agricultural challenges. Another important characteristic is its holistic approach, where agricultural practices are integrated with ecological, social, and cultural dimensions. For example, crop cultivation is often linked with livestock management, forestry, and water conservation, creating a balanced and sustainable system. ITK is also characterized by its reliance on locally available resources, which reduces the need for external inputs and enhances self-reliance among farmers. It is inherently sustainable, as it emphasizes conservation of natural resources, biodiversity, and ecological balance. Furthermore, ITK is community-based and transmitted orally, reflecting collective knowledge rather than individual ownership (Pandey and Verma, 2018).

Historical Evolution and Traditional Foundations

The historical roots of indigenous agricultural knowledge in India can be traced to ancient civilizations, where agriculture was practiced in harmony with natural cycles. Early farming communities developed techniques such as crop rotation, mixed cropping, and organic manuring to maintain soil fertility and productivity. Ancient texts and traditional practices indicate a deep understanding of soil health, seasonal variations, and crop diversity.

Over time, these practices were refined and adapted to local conditions, resulting in a diverse range of agricultural systems across the country. For instance, the rice-based systems of eastern India, millet-based systems of arid regions, and terrace farming in hilly areas all reflect region-specific adaptations. These traditional systems were inherently resilient, enabling farmers to cope with environmental uncertainties such as droughts, floods, and pest outbreaks.

Despite the introduction of modern technologies, many traditional practices continue to persist, particularly among small and marginal farmers. These practices serve as a testament to the enduring relevance of indigenous knowledge in contemporary agriculture (Sharma et al., 2022).

Indigenous Knowledge in Soil Health and Nutrient Management

Soil fertility management is a cornerstone of indigenous agricultural practices. Farmers have long recognized the importance of maintaining soil health through organic inputs and natural processes. The application of farmyard manure, compost, green manure, and crop residues enhances soil organic matter, improves soil structure, and promotes microbial activity. Traditional practices such as crop rotation and intercropping contribute to balanced nutrient utilization and reduce the risk of nutrient depletion. Leguminous crops are often included in cropping systems to fix atmospheric nitrogen and improve soil fertility. The use of ash and plant residues as soil amendments reflects a deep understanding of nutrient recycling and resource conservation. Indigenous methods also emphasize minimal soil disturbance, which helps preserve soil structure and prevent erosion. Mulching with crop residues reduces moisture loss, regulates soil temperature, and suppresses weed growth. These practices collectively contribute to long-term soil sustainability and productivity.

Biodiversity Conservation and Agroecological Stability

One of the most significant contributions of indigenous knowledge is the conservation of agricultural biodiversity. Traditional farming systems promote the cultivation of diverse crop species and varieties, which enhances genetic diversity and ecosystem resilience. Mixed cropping and intercropping systems create a more stable agroecosystem by reducing the risk of total crop failure. Indigenous crop varieties, often referred to as landraces, are well adapted to local environmental conditions and exhibit resistance to pests, diseases, and climatic stresses. These varieties require fewer inputs and are more resilient to environmental fluctuations, making them crucial for sustainable agriculture. The integration of trees, crops, and livestock in traditional agroforestry systems further enhances biodiversity and ecological balance. These systems provide multiple benefits, including improved soil fertility, enhanced carbon sequestration, and diversified income sources for farmers.

Indigenous Pest and Disease Management Practices

Indigenous pest and disease management practices are based on ecological principles and utilize locally available resources. Farmers use a variety of botanical extracts, such as neem, garlic, and chili, to control pests. These natural formulations are effective, biodegradable, and environmentally safe. Cultural practices such as crop rotation, timely sowing, and field sanitation play a crucial role in preventing pest outbreaks. The use of ash, cow urine, and plant-based preparations reflects a deep understanding of pest ecology and plant health. Seed treatment using traditional methods helps protect crops from seed-borne pathogens and improves germination rates. These practices reduce dependence on chemical pesticides and contribute to the preservation of beneficial organisms and ecological balance (Hiremath et al., 2021).

Water Resource Management and Conservation

Water management is a critical component of sustainable agriculture, and indigenous knowledge offers a wide range of solutions for efficient water use. Traditional systems such as tanks, step wells, and canals have been used for centuries to store and distribute water. In rainfed areas, farmers employ techniques such as contour bunding, terracing, and mulching to conserve soil moisture and prevent erosion. These practices enhance water retention and improve crop productivity under limited water conditions. Traditional irrigation systems are often community-managed, ensuring equitable distribution of water resources. The emphasis on water conservation and efficient use reflects a sustainable approach to resource management.

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Climate Resilience and Adaptive Strategies

Indigenous knowledge plays a vital role in enhancing climate resilience by providing adaptive strategies to cope with environmental variability. Farmers use traditional indicators, such as changes in animal behaviour, flowering patterns, and wind direction, to predict weather conditions. Crop diversification and staggered planting are common practices that reduce the risk of crop failure due to unpredictable weather. The selection of drought-tolerant and flood-resistant varieties further enhances resilience. These adaptive strategies are particularly important in the context of climate change, where increasing variability in weather patterns poses significant challenges to agricultural production.

Indigenous Knowledge in Livestock and Integrated Farming

Indigenous knowledge extends to livestock management and integrated farming systems, which are essential components of sustainable agriculture. Ethno-veterinary practices involve the use of medicinal plants and traditional remedies to treat animal diseases, reducing dependence on synthetic drugs. Integrated farming systems combine crops, livestock, fisheries, and agroforestry, creating a synergistic system where waste from one component serves as input for another.

This enhances resource use efficiency, reduces external inputs, and improves overall farm productivity. Such systems are particularly beneficial for small and marginal farmers, as they provide multiple sources of income and reduce risk.

Socio-Cultural and Economic Dimensions

Indigenous knowledge is deeply embedded in the socio-cultural fabric of rural communities. Agricultural practices are often linked with cultural traditions, rituals, and festivals, reflecting a holistic relationship between humans and nature. Knowledge sharing occurs through community interactions, ensuring the continuity of traditional practices. Economically, ITK-based practices are cost-effective and accessible to resource-poor farmers. By relying on locally available resources, these practices reduce production costs and enhance profitability. They also promote self-reliance and reduce vulnerability to market fluctuations (Patil, 2023).

Integration with Modern Agricultural Science

The integration of indigenous knowledge with modern scientific approaches offers significant opportunities for sustainable agricultural development. Scientific validation of traditional practices can enhance their credibility and facilitate their adoption on a larger scale. Participatory research approaches involving farmers, scientists, and extension workers are essential for effective integration. These approaches ensure that innovations are context-specific and address local needs. The use of digital technologies for documenting and disseminating ITK can further enhance its reach and impact. Blending traditional wisdom with modern science can lead to the development of innovative and sustainable agricultural practices.

Challenges in Preservation and Utilization

Despite its importance, indigenous knowledge faces several challenges. Rapid modernization and changing socio-economic conditions have led to the erosion of traditional knowledge systems. Younger generations are increasingly adopting modern practices, resulting in a decline in the transmission of ITK. The lack of systematic documentation and scientific validation limits the recognition and utilization of indigenous knowledge. Issues related to intellectual property rights and biopiracy further complicate its preservation. Addressing these challenges requires coordinated efforts from policymakers, researchers, and local communities.

Policy Framework and Institutional Support in India

The Government of India and various research institutions have recognized the importance of indigenous knowledge in sustainable agriculture. Initiatives aimed at documenting and validating ITK are being undertaken by organizations such as the Indian Council of Agricultural Research. Policies promoting organic farming, natural farming, and agroecology are aligned with traditional knowledge systems. Efforts to conserve indigenous crop varieties and promote farmer-led innovations are essential for mainstreaming ITK. Strengthening extension services and encouraging community participation are critical for the effective implementation of these initiatives.

Future Prospects and Strategic Way Forward

The future of sustainable agriculture in India depends on the effective integration of indigenous traditional knowledge with modern scientific advancements. There is a need for systematic documentation, validation, and dissemination of ITK to ensure its preservation. Capacity building, awareness programs, and community participation are essential for promoting traditional knowledge systems. Digital platforms can play a significant role in sharing knowledge and connecting farmers with researchers and policymakers. Policies should focus on protecting the intellectual property rights of indigenous communities and ensuring equitable benefit-sharing. Encouraging interdisciplinary research and participatory approaches will further enhance the adoption of ITK.

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Conclusion

Indigenous Traditional Knowledge represents a valuable and underutilized resource for sustainable agricultural development in India. It offers environmentally sustainable, economically viable, and socially inclusive solutions to contemporary agricultural challenges. By integrating traditional wisdom with modern scientific approaches, it is possible to develop resilient and sustainable agricultural systems. Preserving and promoting ITK is essential not only for agricultural sustainability but also for safeguarding cultural heritage and ensuring long-term food security.

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Integrated Pest Management: Eco-Friendly Approaches for Horticultural Crop Protection

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Shri. A. N. Surpam[1], Nicky Bansod[2], Dr.Punam Madavi[3], Dr.V. D. Tayade[4]

[1]Junior Research Assistant, Bhausaheb Fundkar Government College of Agriculture, Buldhana (Dr. PDKV., Akola), Maharashtra.

[2]Assistant Professor of Agril. Entomology, SVGI, College of Agriculture, Jalgaon, Jamod, Maharashtra.

[3]Assistant Professor (C) of Agril. Entomology, Bhausaheb Fundkar Government College of Agriculture, Buldhana, Maharashtra.

[4]Assistant Professor (C) of Horticulture, Bhausaheb Fundkar Government College of Agriculture, Buldhana, Maharashtra.

Abstract

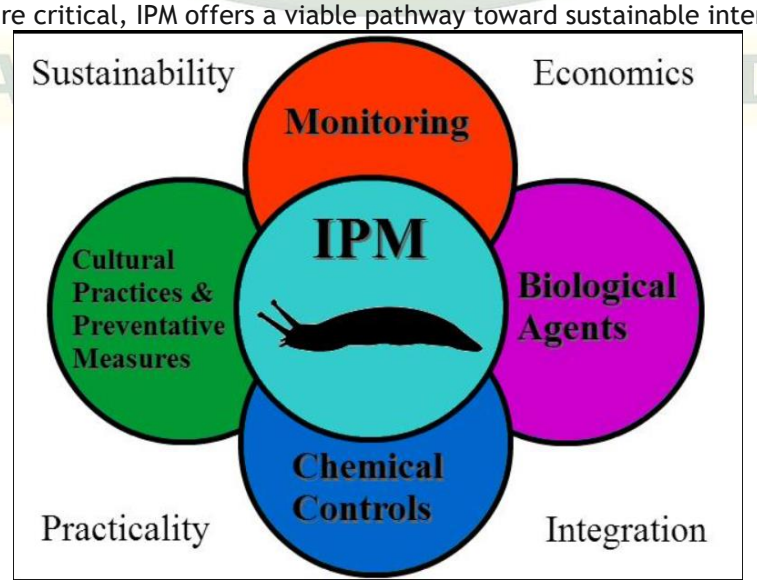
Integrated Pest Management (IPM) represents a sustainable and environmentally sound approach to managing pests in horticultural systems. By integrating biological, cultural, mechanical, and chemical strategies, IPM minimizes economic losses while reducing ecological risks associated with indiscriminate pesticide use. Horticultural crops, including fruits, vegetables, and ornamentals, are particularly vulnerable to pest pressures due to their high economic value and intensive cultivation practices. This review provides an in-depth analysis of IPM principles, eco-friendly pest control strategies, and their application in horticulture. It highlights biological control agents, botanicals, cultural practices, and technological advancements such as precision agriculture and pest forecasting. The article also discusses challenges, future prospects, and policy implications for promoting sustainable pest management in horticultural crops.

Introduction

Horticulture plays a pivotal role in enhancing nutritional security, livelihood generation, and agricultural diversification, especially in countries like India where fruits, vegetables, spices, plantation crops, and ornamental plants contribute significantly to GDP and export earnings. However, horticultural crops are inherently more susceptible to pest infestations compared to field crops due to their succulent tissues, extended cropping cycles, and favourable microclimatic conditions.

The excessive reliance on synthetic pesticides during the Green Revolution era resulted in short-term pest suppression but led to long-term ecological disturbances. These include pesticide resistance, resurgence of secondary pests, destruction of beneficial organisms, environmental pollution, and accumulation of toxic residues in food chains. Consequently, there has been a paradigm shift toward sustainable pest management strategies.

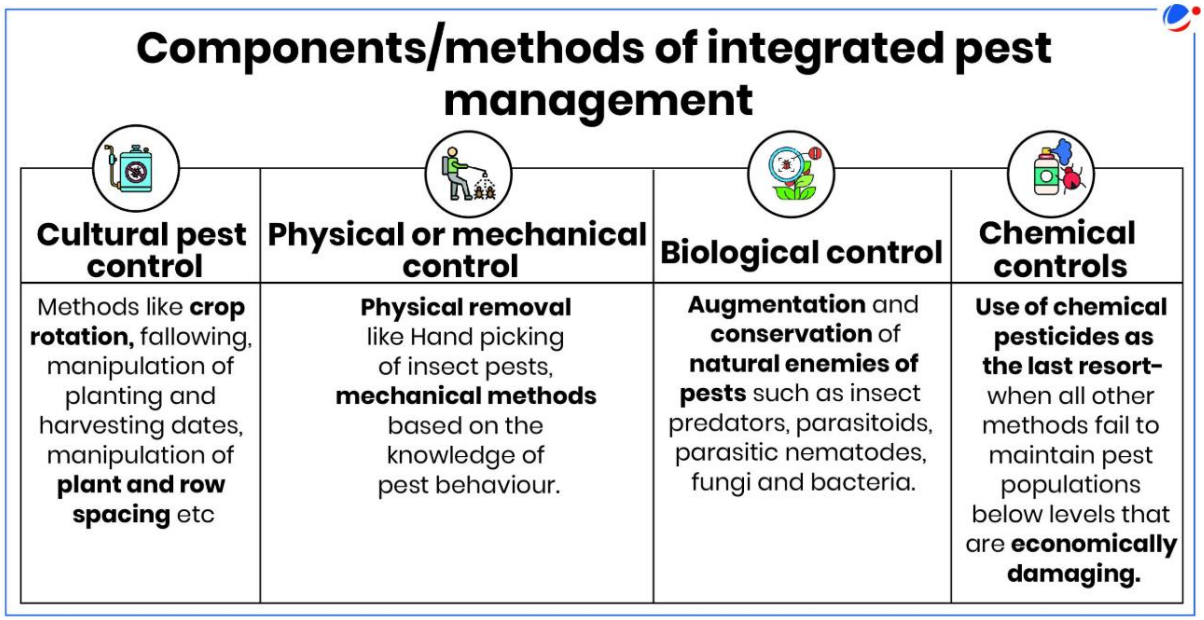
Integrated Pest Management (IPM) has emerged as a scientifically sound and ecologically balanced approach that integrates multiple compatible tactics to manage pest populations below economic injury levels. The concept emphasizes ecological harmony, economic viability, and social acceptability (Kogan et al., 1998). In horticultural systems, where produce quality and safety are critical, IPM offers a viable pathway toward sustainable intensification.



Ecological Basis and Conceptual Framework of IPM

IPM is deeply rooted in ecological principles, recognizing that pest populations are part of a complex agroecosystem involving interactions among crops, pests, natural enemies, and environmental factors. Understanding these interactions is crucial for designing effective pest management strategies. The agroecosystem approach considers biodiversity as a key factor in maintaining ecological balance. Higher biodiversity enhances ecosystem resilience and reduces pest outbreaks by supporting natural enemies. IPM promotes functional biodiversity through habitat manipulation and conservation practices.

The concept of economic threshold level (ETL) is central to IPM. It defines the pest population level at which control measures must be initiated to prevent economic damage. This approach avoids unnecessary pesticide applications and ensures cost-effective pest management. Another critical aspect is the emphasis on preventive rather than curative measures. By creating unfavourable conditions for pest establishment and proliferation, IPM reduces the likelihood of severe infestations.



Detailed Components of Eco-Friendly IPM Strategies

1. Advanced Biological Control Strategies: Biological control in modern IPM extends beyond classical predator-prey relationships and includes conservation, augmentation, and introduction of natural enemies. Conservation biological control focuses on protecting existing natural enemies by minimizing pesticide use and enhancing habitats through flowering plants, hedgerows, and cover crops. Augmentative biological control involves mass rearing and periodic release of natural enemies such as *Trichogramma chilonis, Chrysoperla carnea*, and *Encarsia formosa*. These agents have shown significant success in managing lepidopteran pests and whiteflies in vegetable and ornamental crops. Microbial biocontrol agents, including bacteria, fungi, viruses, and nematodes, are increasingly being utilized. Bacillus thuringiensis produces endotoxins that are highly specific to insect larvae, while entomopathogenic fungi like *Metarhizium anisopliae* infect a wide range of insect pests. These agents are environmentally safe and compatible with other IPM components.

2. Botanicals and Plant-Based Pest Control: Botanical pesticides are gaining renewed interest due to their biodegradability and low toxicity. Neem-based formulations are among the most widely used botanicals, acting as repellents, antifeedants, and insect growth regulators. The active compound azadirachtin disrupts molting and reproduction in insects. Other plant-derived compounds such as rotenone, nicotine, and essential oils from plants like eucalyptus and citronella exhibit insecticidal properties. These botanicals are particularly useful in organic horticulture and small-scale farming systems. Recent research focuses on nano-formulations of botanicals to enhance their stability, efficacy, and shelf life, thereby improving their commercial viability.

3. Cultural and Agronomic Interventions: Cultural practices form the first line of defence in IPM. Crop rotation disrupts pest life cycles, particularly for soil-borne pests and pathogens. Intercropping and mixed cropping systems reduce pest colonization and enhance natural enemy populations. Adjusting planting dates can help crops escape peak pest periods, while proper spacing and pruning improve air circulation and reduce disease incidence. Soil health management through organic amendments and biofertilizers enhances plant vigour and resistance to pests. Trap cropping is another effective strategy where highly attractive plants are grown to divert pests away from the main crop. For example, marigold is used as a trap crop for *Helicoverpa armigera* in tomato fields.

4. Mechanical and Physical Innovations: Mechanical methods, though traditional, are highly effective and environmentally benign. Hand removal of pests, use of barriers such as nets and row cover and pruning of infested plant parts are commonly practiced in horticulture. Physical methods such as temperature manipulation, solarization, and controlled atmospheres are used in protected cultivation and post-harvest pest management. Soil solarization, for instance, effectively controls soil-borne pathogens and nematodes by raising soil temperature using transparent polyethylene sheets. Advanced trapping systems, including pheromone traps, kairomone traps, and coloured sticky traps, are widely used for monitoring and mass trapping of pests. These tools provide valuable data for decision-making and reduce pest populations.

5. Host Plant Resistance and Genetic Approaches: Host plant resistance is a sustainable and cost-effective strategy that reduces dependence on external inputs. Resistance mechanisms include antibiosis, antixenosis, and tolerance. Breeding programs have developed resistant varieties in several horticultural crops. Modern biotechnological tools such as marker-assisted selection and genetic engineering have accelerated the development of resistant cultivars. For instance, Bt brinjal has been developed to resist shoot and fruit borer, significantly reducing pesticide use. Emerging technologies such as CRISPR-based genome editing hold great promise for developing pest-resistant crops with high precision and minimal off-target effects.

6. Judicious Chemical Use and Resistance Management: Chemical pesticides, when used judiciously, remain an important component of IPM. The focus is on using selective, biodegradable, and low-toxicity pesticides that target specific pests while sparing beneficial organisms. Resistance management strategies include rotating pesticides with different modes of action, using recommended doses, and avoiding repeated applications of the same chemical. Integrated approaches combining chemicals with biological control enhance overall effectiveness.

Digital and Smart IPM Technologies

The integration of digital technologies into IPM has revolutionized pest management. Remote sensing and drone-based surveillance enable early detection of pest infestations and assessment of crop health over large areas. Artificial intelligence and machine learning algorithms are being used to develop predictive models for pest outbreaks based on weather data, crop stage, and historical trends. These models provide real-time recommendations to farmers. Mobile-based advisory systems and decision support tools have improved knowledge dissemination and adoption of IPM practices. These technologies are particularly beneficial in developing countries where access to extension services is limited.

Climate Change and IPM

Climate change is altering pest dynamics by influencing their distribution, life cycles, and population dynamics. Rising temperatures and changing precipitation patterns are expected to increase pest pressure in horticultural crops. IPM strategies must be adapted to address these challenges by incorporating climate-resilient practices such as diversified cropping systems, resilient varieties, and improved forecasting models. Understanding pest ecology under changing climatic conditions is crucial for developing effective management strategies.

Socio-Economic and Environmental Benefits of IPM

IPM offers multiple benefits beyond pest control. It reduces production costs by minimizing pesticide use and enhances farmer profitability. The reduction in chemical residues improves food safety and marketability, particularly in export-oriented horticulture. Environmentally, IPM conserves biodiversity, improves soil health, and reduces pollution of air, water, and soil. It also mitigates the negative impacts of agriculture on non-target organisms, including pollinators and natural enemies. Socially, IPM promotes farmer awareness, skill development, and community participation. Farmer Field Schools (FFS) have been instrumental in disseminating IPM knowledge and empowering farmers.

Constraints and Limitations

Despite its advantages, IPM adoption remains limited in many regions due to several constraints. Lack of awareness, inadequate training, and limited access to quality inputs hinder its implementation. The initial complexity of IPM practices may discourage farmers accustomed to quick chemical solutions. Institutional support, including extension services, research funding, and policy incentives, is often insufficient. Standardization and quality control of biopesticides remain major challenges.

Future Directions

Future research in IPM should focus on integrating advanced technologies such as genomics, nanotechnology, and artificial intelligence. Development of climate-smart IPM strategies and region-specific pest management packages is essential. Strengthening public-private partnerships, enhancing farmer training programs, and promoting policy support for eco-friendly inputs will accelerate IPM adoption. The integration of IPM with organic and conservation agriculture practices will further enhance sustainability.

Conclusion

Integrated Pest Management represents a holistic and eco-friendly approach to pest control in horticultural crops. By integrating diverse strategies based on ecological principles, IPM ensures sustainable crop production while minimizing environmental and health risks. The successful implementation of IPM requires coordinated efforts across research, extension, and policy domains. As global agriculture moves toward sustainability, IPM will play a central role in achieving resilient and productive horticultural systems.

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Nanotechnology and Precision Tools for Targeted Pest and Disease Management

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Dr. Sudipta Padhan[1]

[1]Assistant Professor cum Junior Scientist, Department of Plant Protection (Entomology), Horticulture College, Khuntpani, Chaibasa, Birsa Agricultural University, Birsa, Jharkhand.

Abstract

Nanotechnology has emerged as a transformative innovation in agricultural sciences, particularly in the domain of pest and disease management. The manipulation of materials at the nanoscale has enabled the development of highly efficient, targeted, and environmentally sustainable crop protection strategies. Nano-enabled formulations, smart delivery systems, and advanced diagnostic tools have significantly improved the precision and effectiveness of pest control while minimizing non-target effects and ecological risks. The integration of nanotechnology with precision agriculture tools such as sensors, drones, and artificial intelligence has further enhanced site-specific management practices. This review provides an in-depth and expanded analysis of nanotechnology-based approaches for pest and disease management, focusing on mechanisms, applications, environmental implications, and future prospects for sustainable agriculture.

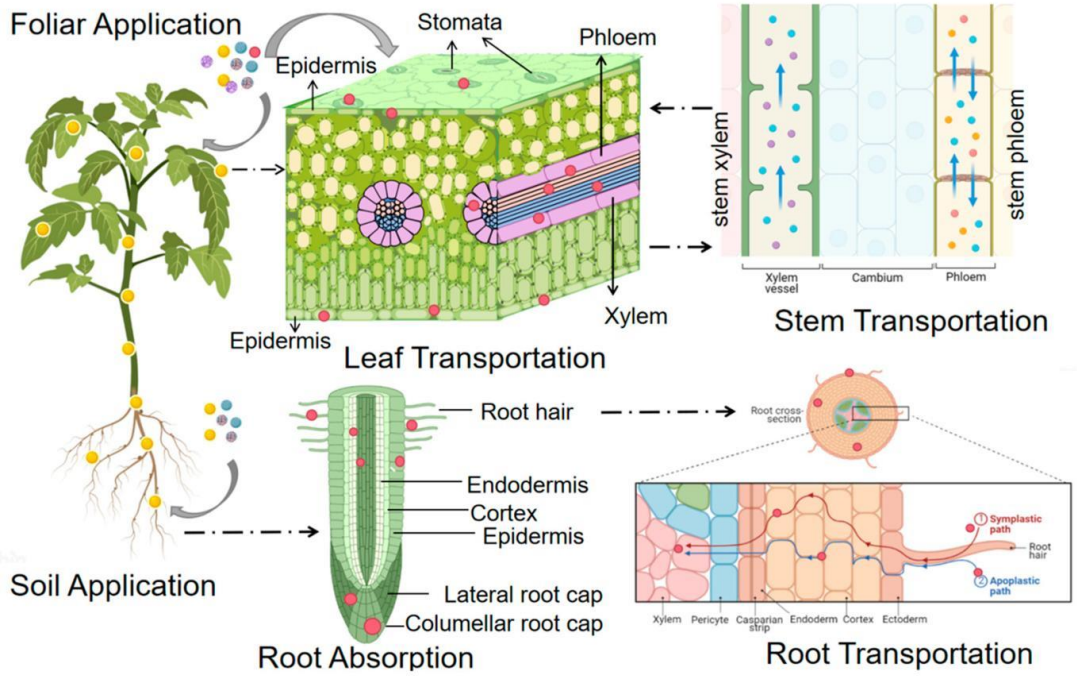
Introduction

Modern agriculture is confronted with the dual challenge of increasing food production while maintaining environmental sustainability. Biotic stresses, including insect pests, fungal pathogens, bacterial infections, and viral diseases, are responsible for substantial crop losses worldwide. Conventional pesticide-based approaches, although widely used, often lead to issues such as resistance development, environmental contamination, residue accumulation, and adverse effects on beneficial organisms.

In response to these challenges, nanotechnology has emerged as a promising alternative, offering precise and efficient solutions for crop protection. By enabling controlled delivery and targeted action of agrochemicals, nanotechnology addresses many of the limitations associated with traditional pest management practices. Furthermore, the integration of nanotechnology with precision agriculture tools has paved the way for data-driven and site-specific interventions, enhancing the overall efficiency of agricultural systems.

Principles and Scope of Nanotechnology in Plant Protection

Nanotechnology involves the design and application of materials at dimensions typically ranging from 1 to 100 nanometers. At this scale, materials exhibit unique physicochemical properties that differ significantly from their bulk counterparts. These properties include enhanced surface area, increased reactivity, improved solubility, and the ability to interact closely with biological systems.



In the context of plant protection, nanotechnology encompasses a wide range of applications, including nano-pesticides, nano-fungicides, nano-sensors, and nano-enabled delivery systems. These technologies are designed to improve the efficiency, specificity, and sustainability of pest and disease management strategies. The scope of nanotechnology extends beyond pest control to include disease diagnostics, nutrient delivery, and stress monitoring, making it a versatile tool in modern agriculture.

Physicochemical Characteristics and Functionalization of Nanomaterials

The performance of nanomaterials in agricultural applications is largely determined by their physicochemical properties. Particle size plays a crucial role in determining the penetration and distribution of nanoparticles within plant tissues and microbial cells. Smaller nanoparticles exhibit higher surface area-to-volume ratios, leading to increased reactivity and biological activity.

Surface charge influences the interaction of nanoparticles with plant surfaces and microbial membranes. Positively charged nanoparticles tend to adhere more strongly to negatively charged biological surfaces, enhancing their effectiveness. Surface functionalization further improves the specificity and stability of nanomaterials. By attaching ligands, polymers, or biomolecules to nanoparticle surfaces, researchers can design targeted delivery systems that interact selectively with specific pests or pathogens.

The morphology and structural characteristics of nanoparticles, including their shape and porosity, also influence their performance. These properties can be tailored to optimize the delivery and release of active ingredients, thereby improving the efficiency of pest and disease management strategies.

Nano-Formulations and Controlled Release Mechanisms

Nano-formulations represent a major advancement in pesticide technology, offering controlled release and targeted delivery of active ingredients. These formulations include nano-emulsions, nano-capsules, nanospheres, and nanogels, each designed to enhance the stability and effectiveness of agrochemicals.

Nanoencapsulation protects active ingredients from environmental degradation caused by factors such as ultraviolet radiation, temperature fluctuations, and microbial activity. It also improves the solubility of hydrophobic compounds, increasing their bioavailability and efficacy. Controlled release mechanisms ensure that active ingredients are released gradually over time, maintaining effective concentrations and reducing the need for repeated applications.

These nano-formulations also enhance the adhesion of pesticides to plant surfaces, reducing losses due to runoff and volatilization. As a result, lower quantities of pesticides are required to achieve the desired effect, contributing to environmental sustainability and cost efficiency. In addition, advanced formulations are increasingly designed to exhibit multi-functional behaviour, combining protective encapsulation with targeting ligands and stimuli-responsive release properties. Such systems ensure that the active compound remains inert during transport and storage but becomes highly active upon reaching the target site.

Smart Nanocarriers and Stimuli-Responsive Delivery Systems

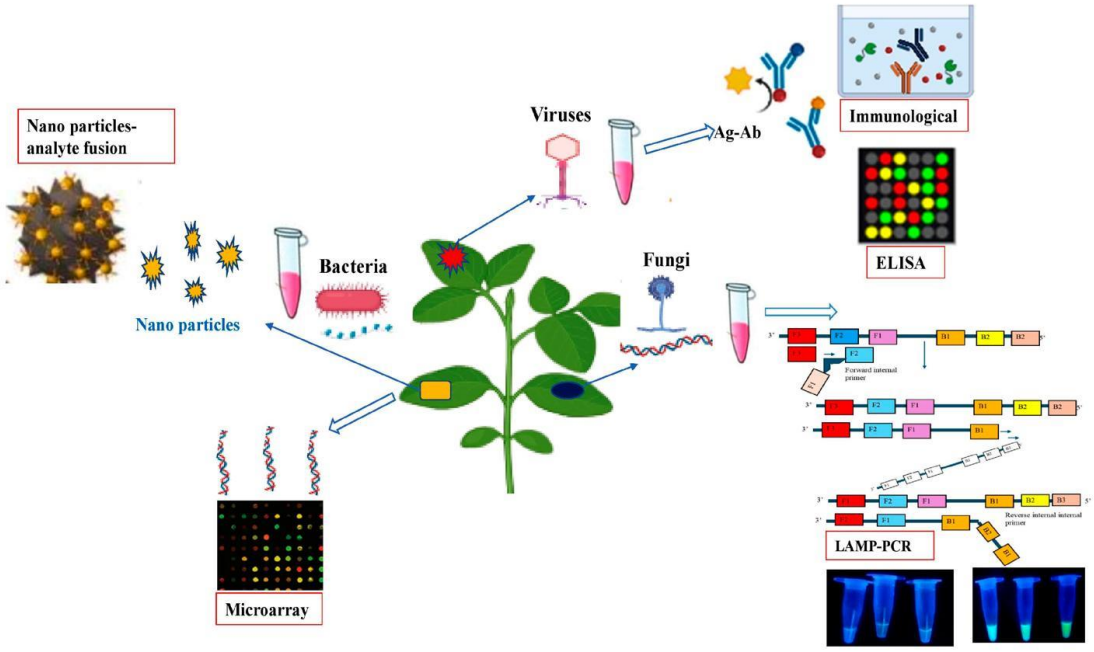
The development of smart nanocarriers represents a significant breakthrough in precision pest management. These systems are engineered to respond to specific environmental stimuli, such as pH changes, temperature variations, light exposure, or enzymatic activity. This responsiveness enables the selective release of active ingredients only under conditions associated with pest infestation or disease infection.

For instance, pH-responsive nanocarriers can release fungicides in acidic environments typical of fungal infections, while enzyme-responsive systems can detect pest-specific enzymes and trigger the release of insecticides. Such targeted delivery mechanisms significantly enhance the precision and effectiveness of pest management strategies.

The use of smart nanocarriers also reduces the risk of non-target effects and environmental contamination. By ensuring that agrochemicals are released only at the site of action, these systems minimize exposure to beneficial organisms and reduce the overall chemical load in the environment. This aligns with the principles of integrated pest management and sustainable agriculture.

Nano-Sensors and Precision Diagnostics

The early detection of pests and diseases is critical for effective management and minimizing crop losses. Nano-sensors have emerged as highly sensitive and specific tools for real-time monitoring of plant health and pathogen presence. These sensors utilize nanomaterials such as carbon nanotubes, quantum dots, and metal nanoparticles to detect biological signals at very low concentrations.



Nano-sensors can identify pathogen-specific biomarkers, volatile organic compounds released by infected plants, and stress-related metabolites. The integration of these sensors with wireless communication technologies enables real-time data transmission and analysis, allowing farmers to make informed decisions regarding pest management. When combined with artificial intelligence and machine learning algorithms, nano-sensor data can be used to predict pest outbreaks and optimize intervention strategies. This data-driven approach enhances the efficiency and sustainability of crop protection practices.

Applications in Disease Management

Nanotechnology offers innovative approaches for managing plant diseases caused by fungi, bacteria, and viruses. Metallic nanoparticles such as silver, copper, and zinc oxide exhibit strong antimicrobial properties. These nanoparticles disrupt microbial cell membranes, generate reactive oxygen species, and interfere with essential cellular processes, leading to pathogen inhibition.

Nano-formulated fungicides enhance the penetration and distribution of active ingredients within plant tissues, improving their effectiveness. Additionally, nanotechnology facilitates RNA interference-based disease management, where nanocarriers deliver double-stranded RNA molecules to silence pathogen genes. This approach provides a highly targeted and environmentally friendly alternative to conventional fungicides. The use of nanotechnology in disease management also extends to the development of antiviral agents and plant immune stimulants, which enhance the natural defence mechanisms of plants.

Applications in Insect Pest Management

Insect pests pose a major threat to agricultural productivity, and their management is becoming increasingly challenging due to resistance development and environmental concerns. Nanotechnology-based approaches offer innovative solutions for insect pest control by improving the delivery and effectiveness of insecticides.

Nano-insecticides enhance the stability and persistence of active ingredients, ensuring sustained release and prolonged protection. Encapsulation protects pesticides from environmental degradation and improves their bioavailability. Nanotechnology also enables the development of pheromone delivery systems, which are used for pest monitoring and control.

In addition, nanoparticles can interfere with insect physiological processes, such as digestion and nervous system function, providing alternative modes of action. These approaches help in managing resistance and reducing reliance on conventional chemical pesticides.

Integration with Precision Agriculture

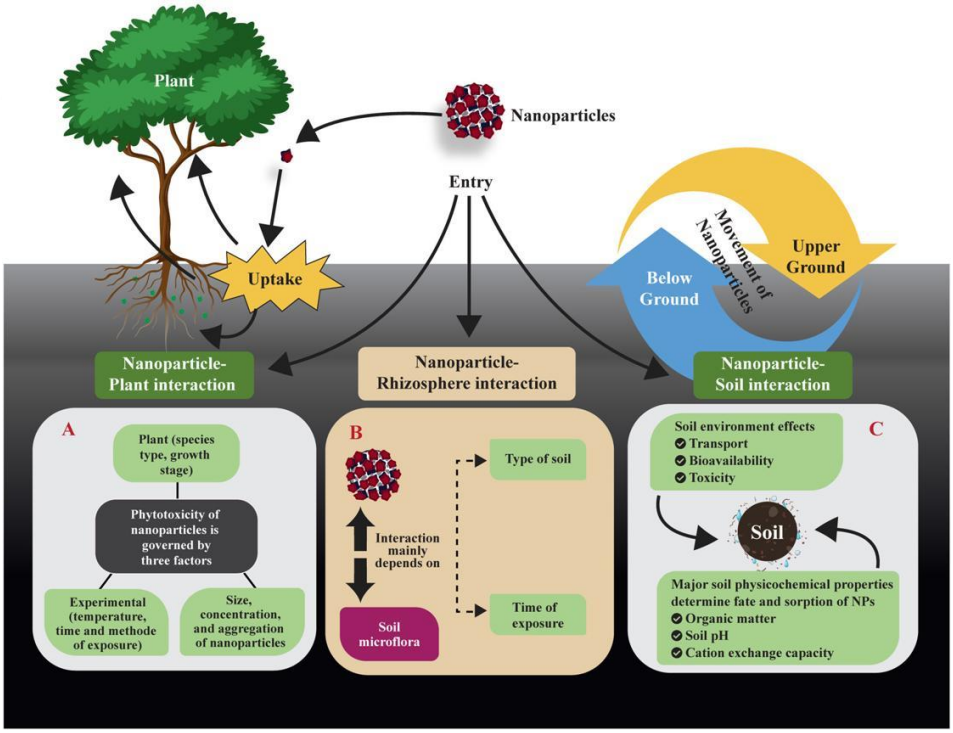
The integration of nanotechnology with precision agriculture tools represents a major advancement in crop protection. Technologies such as drones, remote sensing, GPS, and artificial intelligence enable site-specific application of nano-formulations, reducing input wastage and environmental impact.



Precision tools allow farmers to monitor pest populations and disease incidence in real time, enabling targeted interventions. This approach not only improves the efficiency of pest management but also reduces costs and enhances crop productivity.

Environmental Fate, Safety, and Risk Assessment

While nanotechnology offers numerous advantages, its environmental and health implications must be carefully evaluated. Nanoparticles can interact with soil, water, and plant systems, influencing microbial communities and ecological processes. Their small size and high reactivity raise concerns about potential toxicity and accumulation in the food chain.



Comprehensive risk assessment studies are required to evaluate the safety of nanomaterials in agricultural applications. The development of biodegradable and eco-friendly nanoparticles is a key area of research aimed at minimizing environmental risks.

Challenges, Research Needs and Future Directions

Despite significant advancements, several challenges remain in the application of nanotechnology for pest and disease management. These include high production costs, scalability issues, lack of standardized protocols, and limited field-level validation. Regulatory frameworks for nano-pesticides are still evolving, and clear guidelines are needed to ensure their safe and effective use.

Future research should focus on developing cost-effective and environmentally sustainable nanomaterials, improving delivery systems, and integrating nanotechnology with advanced digital tools. The convergence of nanotechnology with genomics, artificial intelligence, and precision agriculture is expected to drive the next generation of crop protection strategies.

Conclusion

Nanotechnology and precision tools have the potential to revolutionize pest and disease management in agriculture by providing targeted, efficient, and environmentally sustainable solutions. The development of nano-formulations, smart delivery systems, and nano-sensors has significantly enhanced the effectiveness of crop protection strategies. While challenges related to safety, cost, and regulation remain, continued research and innovation will pave the way for the widespread adoption of nanotechnology in agriculture, contributing to global food security and sustainable development.

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Climate Change Impact on Pest Dynamics and Adaptation of IPM Strategies

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Dr. Sudipta Padhan[1]

[1]Assistant Professor cum Junior Scientist, Department of Plant Protection (Entomology), Horticulture College, Khuntpani, Chaibasa, Birsa Agricultural University, Birsa.

Abstract

Climate change is increasingly recognized as a major determinant influencing agricultural pest dynamics across the globe. Rising temperatures, altered precipitation regimes, elevated atmospheric carbon dioxide levels, and increased frequency of extreme weather events are collectively reshaping pest ecology, biology, and distribution patterns. These environmental changes have resulted in enhanced pest survival, faster developmental rates, increased voltinism, and complex alterations in pest-host-natural enemy interactions. Consequently, pest outbreaks are becoming more frequent and severe, posing significant threats to global food security. This review provides an in-depth examination of the multifaceted impacts of climate change on pest dynamics and critically evaluates the need for adaptation of Integrated Pest Management (IPM) strategies. Emphasis is placed on ecological resilience, climate-informed decision-making, and technological innovations for sustainable pest management under changing climatic scenarios.

Introduction

Agricultural ecosystems are highly sensitive to climatic variability, and pests constitute one of the most dynamic components of these systems. Climate change, driven primarily by anthropogenic greenhouse gas emissions, has altered global temperature regimes, precipitation patterns, and atmospheric composition. These changes are particularly significant in tropical and subtropical regions, where agricultural productivity is already constrained by environmental variability.

Pests, including insects, plant pathogens, nematodes, and weeds, respond rapidly to environmental changes due to their short generation times, high reproductive potential, and strong dependence on temperature. Even minor fluctuations in climatic variables can trigger substantial changes in pest population dynamics. The consequences include increased frequency of pest outbreaks, expansion of pest ranges, and emergence of new pest complexes.

Integrated Pest Management has traditionally been based on ecological principles, combining biological, cultural, mechanical, and chemical methods. However, climate change is challenging the stability and predictability of these systems. There is a growing need to redesign IPM frameworks to incorporate climate resilience and adaptability.

Climate Change Drivers and their Physiological and Ecological Effects on Pests

Temperature remains the most critical factor influencing insect physiology and development. As ectothermic organisms, insects rely on external temperatures to regulate metabolic processes. Rising temperatures accelerate biochemical reactions, leading to faster development, increased feeding rates, and higher reproductive output. This often results in an increase in the number of generations per year, a phenomenon that significantly intensifies pest pressure (Deutsch et al., 2018).

Thermal thresholds determine pest survival and distribution. With increasing temperatures, previously inhospitable regions are becoming suitable for pest establishment. However, extreme heat may also exceed upper tolerance limits for certain species, creating complex and region-specific responses. Changes in precipitation patterns influence pest populations both directly and indirectly. High humidity favours the proliferation of fungal and bacterial pathogens, enhancing disease incidence. Conversely, drought conditions may suppress some pathogens but increase susceptibility of crops to insect pests due to physiological stress.

Elevated atmospheric carbon dioxide levels alter plant physiology by increasing carbon assimilation and reducing nitrogen content. This imbalance affects herbivore nutrition, often leading to compensatory feeding behaviour, where insects consume more plant material to meet their nutritional needs. Such changes amplify crop damage and reduce productivity. Extreme weather events such as heatwaves, floods, and storms disrupt ecological balance. These events can cause sudden fluctuations in pest populations, either by directly affecting survival or by altering habitat conditions. They may also facilitate the dispersal of pests over long distances.

Shifts in Pest Distribution, Range Expansion, and Invasiveness

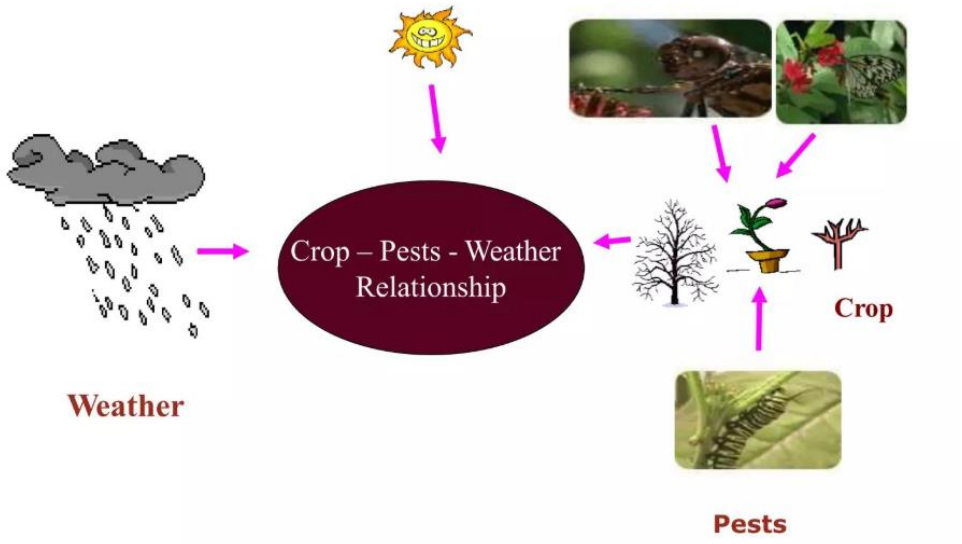
Climate change is driving significant shifts in the geographical distribution of pests. Numerous studies have documented poleward and altitudinal expansions of pest species as global temperatures rise. These shifts are particularly evident in insects and plant pathogens that were previously restricted by low temperature conditions (Bebber et al., 2013). Increased overwintering survival is a critical factor contributing to higher pest populations. Warmer winters reduce

mortality rates, allowing more individuals to survive and reproduce in subsequent seasons. This leads to earlier infestations and prolonged periods of pest activity.

Range expansion is often accompanied by the invasion of new pest species into previously unaffected regions. Invasive pests tend to exhibit high adaptability and reproductive capacity, enabling them to establish rapidly in new environments. The absence of natural enemies in these regions further exacerbates their impact. Climate change also influences migratory behaviour in certain pests. For example, long-distance migratory insects may alter their movement patterns in response to changing wind currents and temperature gradients, leading to unpredictable pest outbreaks.

Phenological Changes and Disruption of Ecological Synchrony

Phenology refers to the timing of biological events such as emergence, reproduction, and migration. Climate change is altering phenological patterns of both pests and their host plants. Warmer temperatures often result in earlier pest emergence, which may lead to mismatches with host plant development stages. Such mismatches can have diverse outcomes. In some cases, pests may benefit from early access to vulnerable plant stages, leading to increased damage. In other cases, lack of synchronization may reduce pest survival. The interaction between pests and natural enemies is also affected by phenological shifts. Parasitoids and predators may fail to align their life cycles with those of their prey, reducing biological control efficiency. These disruptions highlight the complexity of ecological responses to climate change.



Influence on Pest-Plant Interactions and Plant Defense Systems

Climate-induced changes in plant physiology significantly affect pest interactions. Elevated CO_2 levels enhance photosynthetic activity, resulting in increased carbohydrate accumulation but reduced protein content. This change reduces the nutritional quality of plants for herbivorous insects. Plants under climatic stress often exhibit weakened defence mechanisms, including reduced production of defensive chemicals such as phenolics and alkaloids. This makes them more susceptible to pest attacks. Additionally, changes in plant volatile compounds can influence pest behaviour, affecting host selection and feeding patterns. Climate stress may also alter plant morphology, indirectly influencing pest colonization.

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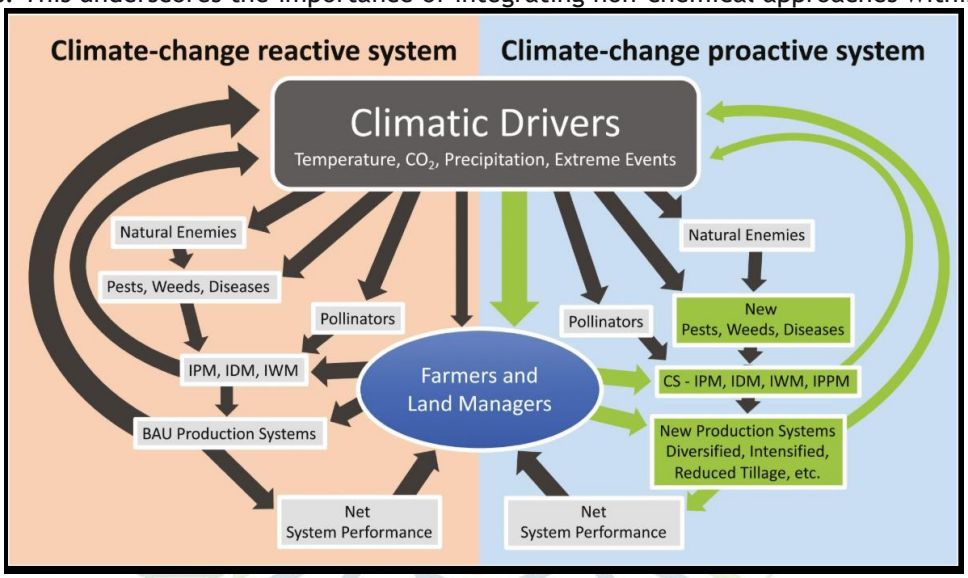
Impact on Natural Enemies and Biological Control Systems

Natural enemies are integral to maintaining ecological balance in agroecosystems. However, climate change can disrupt their populations and effectiveness. Predators and parasitoids often have narrower climatic tolerance ranges compared to pests. As temperatures rise, pests may gain a competitive advantage, leading to reduced effectiveness of biological control. Changes in humidity and temperature can also affect entomopathogenic organisms, altering their infectivity and survival. For instance, reduced humidity may limit the spread of fungal pathogens used in biological control. Extreme climatic events can cause population crashes in natural enemies, leading to long-term disruptions in pest regulation. These challenges necessitate the development of climate-resilient biological control strategies.

Climate Change and Pesticide Resistance Dynamics

Climate change can indirectly influence pesticide resistance in pest populations. Increased number of generations per year accelerates evolutionary processes, including resistance development. Temperature also affects the degradation and efficacy of pesticides. Higher temperatures may reduce pesticide persistence, leading to sub-lethal exposure and

selection of resistant individuals. Increased pest pressure often leads to higher pesticide usage, further intensifying resistance problems. This underscores the importance of integrating non-chemical approaches within IPM frameworks.



Implications for Crop Productivity and Food Security

The combined effects of increased pest pressure, altered ecological interactions, and reduced control efficiency have significant implications for crop yields. Major crops such as rice, wheat, and maize are particularly vulnerable to climate-induced pest damage. In tropical regions, where climatic conditions already favour pest proliferation, the impact is more severe. Smallholder farmers are disproportionately affected due to limited access to resources and adaptive technologies. The economic consequences include increased production costs, reduced yields, and greater risk of crop failure. These challenges pose serious threats to global food security.

Adaptation and Evolution of Climate-Resilient IPM Strategies

Adapting IPM to climate change requires a holistic and flexible approach. Climate-informed pest forecasting systems can help anticipate outbreaks and guide timely interventions. Host plant resistance remains a key strategy. Breeding programs should focus on developing varieties that are resistant to multiple pests and tolerant to climatic stresses. Ecological engineering practices, such as habitat diversification and conservation of natural enemies, enhance resilience. Maintaining biodiversity within agroecosystems strengthens natural pest regulation. Cultural practices, including crop rotation, altered sowing dates, and improved soil management, can reduce pest incidence under changing climatic conditions. Chemical control should be used judiciously, with emphasis on resistance management and environmental safety.

Role of Advanced Technologies in Climate-Smart Pest Management

Technological innovations are playing a crucial role in adapting pest management to climate change. Remote sensing and GIS technologies enable large-scale monitoring of pest populations and environmental conditions. Artificial intelligence and machine learning models can predict pest outbreaks based on climatic data, enhancing decision-making. Precision agriculture tools, including drones and sensors, allow targeted application of control measures, reducing costs and environmental impact. Digital platforms and mobile applications facilitate rapid dissemination of information, empowering farmers with real-time advisories.

Comprehensive risk assessment studies are required to evaluate the safety of nanomaterials in agricultural applications. The development of biodegradable and eco-friendly nanoparticles is a key area of research aimed at minimizing environmental risks.

Challenges, Research Needs and Future Directions

Despite significant advancements, several challenges remain in the application of nanotechnology for pest and disease management. These include high production costs, scalability issues, lack of standardized protocols, and limited field-level validation. Regulatory frameworks for nano-pesticides are still evolving, and clear guidelines are needed to ensure their safe and effective use.

Policy Frameworks and Institutional Support

Effective adaptation requires strong policy support and institutional frameworks. Governments must invest in climate-smart agriculture and pest management research. Extension services should integrate climate information with pest

management advisories, ensuring that farmers receive timely and relevant guidance. Capacity building and training programs are essential to promote adoption of adaptive IPM practices. Policies should also encourage sustainable practices and reduce reliance on chemical pesticides. International collaboration is critical for addressing transboundary pest issues and sharing knowledge and technologies.

Future Research Needs

Future research should focus on understanding the complex interactions between climate variables, pests, crops, and natural enemies. Long-term monitoring and predictive modelling are essential for anticipating future pest scenarios. There is a need to develop region-specific, climate-resilient IPM packages that consider local agroecological conditions. Interdisciplinary approaches integrating multiple scientific domains will enhance the effectiveness of pest management strategies.

Conclusion

Climate change is profoundly altering pest dynamics, posing significant challenges to agricultural sustainability. Increased pest pressure, shifting distributions, and weakened ecological regulation mechanisms demand urgent adaptation of pest management strategies. Integrated Pest Management remains a cornerstone of sustainable agriculture, but it must evolve to incorporate climate resilience, technological innovation, and ecological sustainability. By adopting adaptive IPM approaches and strengthening institutional support, it is possible to mitigate the impacts of climate change on pest dynamics and ensure global food security.

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Biofortification of Vegetables: Strategies to Enhance Nutritional Quality

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Dr. V. D. Tayade[1], Shri. V. N. Patil[2], Dr. V. G. Kalpande[3], Nicky Bansod[4]

[1]Assistant Professor (C) of Horticulture, Bhausaheb Fundkar Government College of Agriculture, Buldhana (Dr. PDKV., Akola), Maharashtra.

[2]Assistant Professor of Horticulture, Bhausaheb Fundkar Government College of Agriculture, Buldhana (Dr. PDKV., Akola), Maharashtra.

[3]Assistant Professor of Agricultural Botony, Bhausaheb Fundkar Government College of Agriculture, Buldhana (Dr. PDKV., Akola), Maharashtra.

[4]Assistant Professor of Agricultural Entomology, SVGI, College of Agriculture, Jalgaon Jamod, Maharashtra.

Abstract

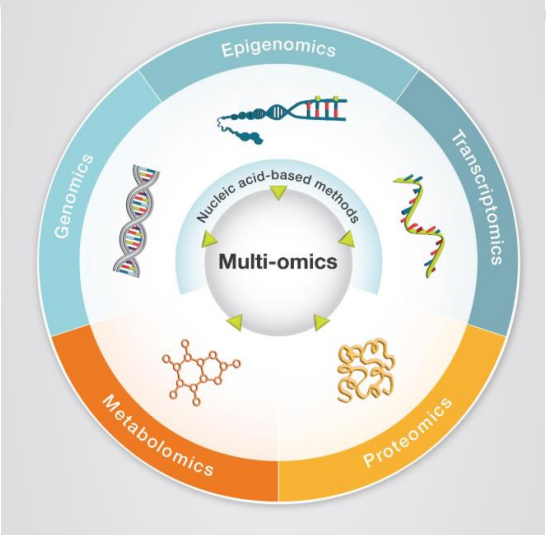
Biofortification of vegetables has emerged as a promising, sustainable strategy to combat micronutrient deficiencies, often referred to as "hidden hunger," affecting millions globally. Unlike conventional supplementation and food fortification approaches, biofortification enhances the intrinsic nutritional value of crops during plant growth through agronomic practices, conventional breeding, and modern biotechnological interventions. Vegetables, being rich sources of vitamins, minerals, antioxidants, and dietary fibre, provide an ideal platform for nutritional enhancement. This review comprehensively explores the concept, importance, and various strategies of vegetable biofortification, including genetic, agronomic, and microbial approaches. It further discusses the physiological mechanisms underlying nutrient accumulation, challenges associated with bioavailability and consumer acceptance, and the future prospects of integrating advanced omics technologies and genome editing tools. Biofortification of vegetables represents a cost-effective, eco-friendly, and scalable solution to improve human nutrition and ensure food security in a changing global climate.

Introduction

Micronutrient malnutrition, often termed hidden hunger, remains one of the most pressing global health concerns, particularly in developing countries such as India where dietary diversity is limited and access to nutrient-rich foods is uneven. Deficiencies of iron, zinc, vitamin A, iodine, and folates are associated with anaemia, impaired cognitive function, compromised immunity, and increased susceptibility to infectious diseases. According to Bouis *et al.*, (2017) biofortification offers a long-term, sustainable solution by enhancing nutrient density in staple and horticultural crops.

Vegetables occupy a central role in human nutrition due to their richness in micronutrients, phytonutrients, antioxidants, and dietary fibre. However, modern agricultural practices focusing on yield maximization have inadvertently led to a decline in nutrient density, a phenomenon often described as "nutritional dilution." Furthermore, soil degradation, imbalanced fertilization, and climate change have exacerbated micronutrient deficiencies in crops.

Biofortification, therefore, represents a paradigm shift in agricultural and nutritional sciences. Unlike post-harvest fortification, which requires industrial processing and infrastructure, biofortification is inherently embedded within the crop itself. Vegetables such as spinach, tomato, carrot, broccoli, and lettuce are particularly suitable targets due to their high consumption rates and nutritional significance.



Conceptual Framework and Types of Biofortification

Biofortification can be broadly categorized into agronomic, genetic (conventional breeding), and transgenic or genome-editing approaches. Each of these strategies operates at different biological and technological levels but shares the common goal of enhancing nutrient density in edible plant parts.

Agronomic biofortification focuses on external inputs and soil-plant interactions, whereas genetic biofortification relies on inherent plant traits. Biotechnological approaches, including transgenic and genome editing techniques, provide precision tools to manipulate metabolic pathways and nutrient transport systems. An integrated approach combining these strategies is increasingly recognized as the most effective method to achieve sustainable biofortification outcomes.

Agronomic Biofortification: Mechanisms and Advances

Agronomic biofortification involves the application of mineral fertilizers, foliar sprays, and soil amendments to enhance nutrient uptake and accumulation in plants. This method is particularly effective for micronutrients such as zinc, iron, selenium, and iodine. The effectiveness of agronomic biofortification depends on several factors, including soil properties, nutrient mobility, plant genotype, and environmental conditions. For example, zinc deficiency is widespread in Indian soils, and its application through soil or foliar methods has significantly improved zinc content in vegetables like spinach and cabbage (Cakmak *et al*. 2008).

Foliar application has gained prominence due to its higher efficiency compared to soil application. It allows direct nutrient absorption through leaves, bypassing soil-related constraints such as fixation and leaching. Nano-fertilizers and chelated micronutrients have further enhanced nutrient use efficiency and minimized environmental losses. Recent research has also explored the role of biochar, compost, and organic amendments in improving soil health and nutrient availability. These materials enhance microbial activity, increase cation exchange capacity, and improve nutrient retention, thereby facilitating better nutrient uptake by plants. Despite its advantages, agronomic biofortification requires repeated applications and may not provide long-term sustainability unless integrated with other approaches.

Conventional Breeding: Genetic Enhancement of Nutrient Density

Conventional breeding remains one of the most widely accepted and sustainable approaches to biofortification. It involves the selection and crossing of plant varieties with desirable traits to develop nutrient-rich cultivars. Genetic variability is the cornerstone of this approach. For instance, significant variation exists in carotenoid content among carrot and tomato genotypes. By selecting high-carotenoid lines, breeders have developed varieties with enhanced provitamin A content.

Marker-assisted selection (MAS) and quantitative trait loci (QTL) mapping have revolutionized conventional breeding by enabling the identification of genes associated with nutrient traits. These tools have accelerated the breeding process and improved the precision of trait selection. However, conventional breeding faces challenges such as linkage drag, long breeding cycles, and limited genetic diversity for certain micronutrients. Additionally, environmental factors can influence gene expression and nutrient accumulation, leading to variability in nutrient content.

Genetic Engineering and Genome Editing

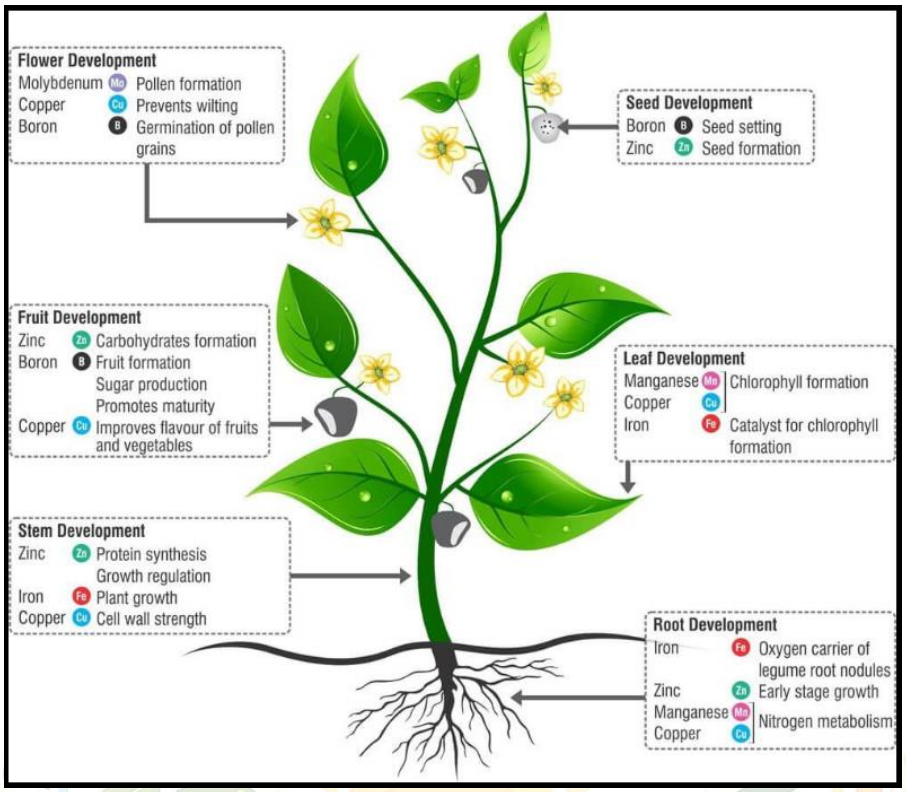
Biotechnological approaches offer unprecedented opportunities to enhance nutritional quality by directly manipulating genes involved in nutrient biosynthesis, transport, and storage. Genetic engineering has been successfully used to increase beta-carotene content in vegetables by introducing genes involved in carotenoid biosynthesis pathways. Similarly, overexpression of ferritin genes has been used to enhance iron content and bioavailability. Genome editing technologies such as CRISPR-Cas systems provide a more precise and efficient alternative to traditional genetic engineering. These tools allow targeted modifications of specific genes without introducing foreign DNA, thereby addressing regulatory and public acceptance concerns (Graham et. al., 2001).

For example, editing genes involved in anti-nutritional factor synthesis can improve nutrient bioavailability. Similarly, modifying transporter genes can enhance nutrient uptake and translocation. Despite their potential, these technologies face challenges related to regulatory approval, ethical considerations, and consumer acceptance, particularly in developing countries.

Physiological and Molecular Basis of Nutrient Accumulation

Understanding the physiological and molecular mechanisms of nutrient uptake and accumulation is essential for the success of biofortification strategies. Nutrient uptake occurs through root systems via specific transport proteins, followed by translocation through vascular tissues. Transporter proteins such as ZIP, NRAMP, and YSL play critical roles in micronutrient transport. These proteins facilitate the movement of zinc, iron, and other micronutrients across cellular membranes. Once inside the plant, nutrients are often chelated with organic molecules such as nicotianamine or stored in vacuoles to prevent toxicity. The remobilization of nutrients during plant growth and development ensures their accumulation in edible tissues.

Gene expression and regulatory networks also play a crucial role in nutrient homeostasis. Transcription factors respond to nutrient availability and regulate the expression of genes involved in uptake and transport. Advances in omics technologies have provided deeper insights into these mechanisms, enabling the identification of key genes and pathways for targeted biofortification.



Role of Soil-Plant-Microbe Interactions

The rhizosphere, a dynamic zone of interaction between plant roots and soil microorganisms, plays a crucial role in nutrient availability and uptake. Beneficial microorganisms such as plant growth-promoting rhizobacteria (PGPR) and mycorrhizal fungi enhance nutrient solubilization and uptake (White & Broadley, 2009).

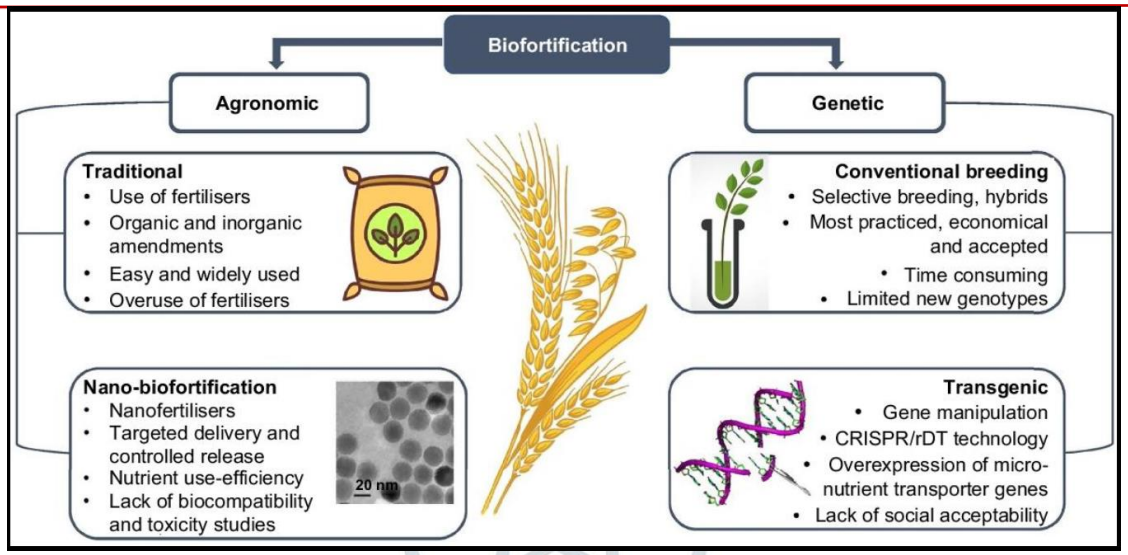
PGPR such as Bacillus and Pseudomonas species produce siderophores that chelate iron and make it available to plants. They also solubilize phosphate and produce phytohormones that stimulate root growth. Arbuscular mycorrhizal fungi (AMF) form symbiotic associations with plant roots, extending their hyphal networks into the soil and enhancing nutrient absorption, particularly phosphorus and micronutrients. The integration of microbial inoculants with agronomic practices represents a promising approach to sustainable biofortification.

Bioavailability, Nutritional Synergy and Human Health Impact

The nutritional impact of biofortified vegetables depends not only on nutrient concentration but also on bioavailability. Anti-nutritional factors such as phytates, oxalates, and tannins can inhibit nutrient absorption. Strategies to improve bioavailability include reducing anti-nutritional compounds, enhancing promoters of nutrient absorption, and modifying food processing methods. For instance, increasing vitamin C content enhances iron absorption, while fermentation and cooking can reduce phytate levels. Biofortified vegetables also contain bioactive compounds such as flavonoids, polyphenols, and carotenoids that have antioxidant properties and contribute to disease prevention. Clinical and field studies have demonstrated that regular consumption of biofortified crops improves micronutrient status, particularly in vulnerable populations.

Environmental and Climate Change Considerations

Climate change poses significant challenges to nutrient availability and crop productivity. Elevated CO_2 levels, temperature fluctuations, and water stress can affect nutrient uptake and accumulation. Biofortification strategies must therefore consider climate resilience. Developing varieties that maintain high nutrient content under stress conditions is essential for ensuring food and nutritional security. Additionally, sustainable agricultural practices such as conservation agriculture, integrated nutrient management, and precision farming can enhance the effectiveness of biofortification under changing climatic conditions.



Socio-Economic and Policy Dimensions

The success of biofortification depends on its adoption by farmers and acceptance by consumers. Awareness programs, extension services, and policy support are crucial for promoting biofortified vegetables. Economic incentives, subsidies, and inclusion of biofortified crops in public distribution systems can enhance adoption rates. Public-private partnerships and international collaborations also play a vital role in scaling up biofortification initiatives.

Challenges and Future Prospects

Despite significant progress, several challenges remain. These include limited genetic variability, environmental influences on nutrient accumulation, and trade-offs between yield and nutrient content. Consumer acceptance, particularly of genetically modified crops, remains a critical barrier. Future research should focus on integrating omics technologies, genome editing, and precision agriculture to develop climate-resilient, nutrient-rich vegetable varieties. The use of nanotechnology and bioengineered microbes also holds great promise.

Conclusion

Biofortification of vegetables represents a holistic and sustainable approach to addressing micronutrient malnutrition. By combining agronomic, genetic, and biotechnological strategies, it is possible to enhance the nutritional quality of vegetables and improve public health outcomes. Continued research, innovation, and policy support are essential to realize the full potential of this transformative approach.

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Role of Mycorrhiza in Enhancing Nutrient Uptake in Horticultural Plants

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Yaswanthika Sai Pakki[1], Hari Sankar Sai Muragadapu[2]

[1]B.Sc. (Hons.) Agriculture, Chaudhary Charan Singh University, Meerut, Uttar Pradesh.

[2]M.Sc. Agriculture, Department of Vegetable Science, College of Agriculture, OUAT, Bhubaneswar, Odisha.

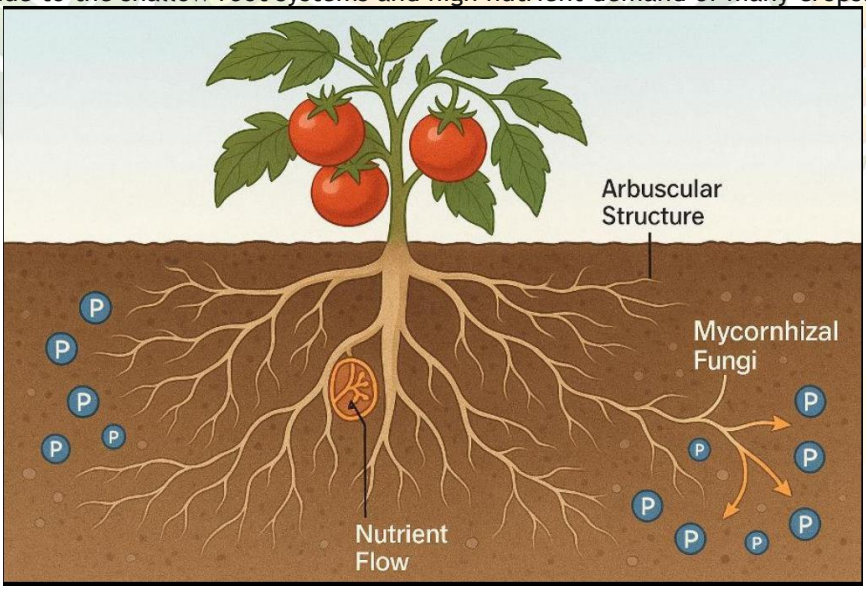
Abstract

Mycorrhizal symbiosis represents one of the most widespread and ecologically significant plant–microbe interactions, playing a crucial role in nutrient acquisition, plant growth, and soil health. In horticultural systems, where high productivity and quality are essential, mycorrhizae offer a sustainable approach to improving nutrient uptake efficiency, particularly for immobile nutrients such as phosphorus and micronutrients. This review provides an expanded and in-depth analysis of the mechanisms through which mycorrhizal fungi enhance nutrient acquisition in horticultural crops, including morphological, physiological, molecular, and biochemical processes. It also discusses ecological interactions, practical applications, constraints, and future research directions. Emphasis is placed on their role in improving plant resilience, soil structure, nutrient cycling, and long-term sustainability of horticultural systems.

Introduction

Horticultural crops are highly input-intensive systems that demand efficient nutrient uptake for optimum productivity, quality attributes, and economic returns. However, a substantial proportion of applied fertilizers remains unavailable to plants due to fixation, leaching, or conversion into insoluble forms. This inefficiency not only reduces crop productivity but also contributes to environmental degradation. In this context, mycorrhizal symbiosis has emerged as a crucial biological strategy for improving nutrient acquisition and resource use efficiency.

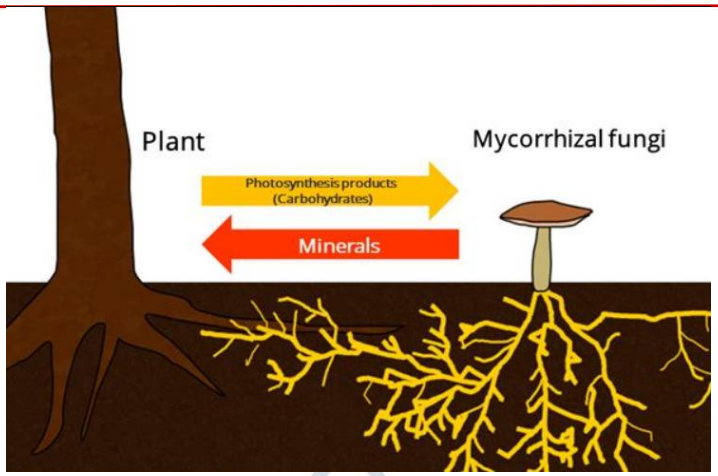
Mycorrhizae, derived from the Greek words “mykes” (fungus) and “rhiza” (root), represent a mutualistic association between plant roots and soil fungi. Approximately 80–90% of terrestrial plant species are known to form mycorrhizal associations, highlighting their evolutionary and ecological significance. In horticulture, these associations are particularly important due to the shallow root systems and high nutrient demand of many crops.



Diversity and Functional Types of Mycorrhizae

Mycorrhizal associations are diverse and vary in structure, host specificity, and functional roles. Among these, arbuscular mycorrhizae dominate horticultural systems. These fungi belong to the phylum Glomeromycota and form intracellular associations characterized by highly branched arbuscules that serve as sites of nutrient exchange.

Ectomycorrhizae, though less common in horticultural crops, are significant in woody fruit trees and forest-based horticulture. These fungi form a mantle around roots and facilitate nutrient exchange through the Hartig net. Orchidaceous and ericoid mycorrhizae are specialized forms that play critical roles in the survival and growth of orchids and ericaceous crops such as blueberry and cranberry. The functional diversity of mycorrhizal fungi allows them to adapt to a wide range of environmental conditions, making them highly valuable in diverse horticultural systems, from open fields to protected cultivation.



Mechanisms of Nutrient Uptake Enhancement

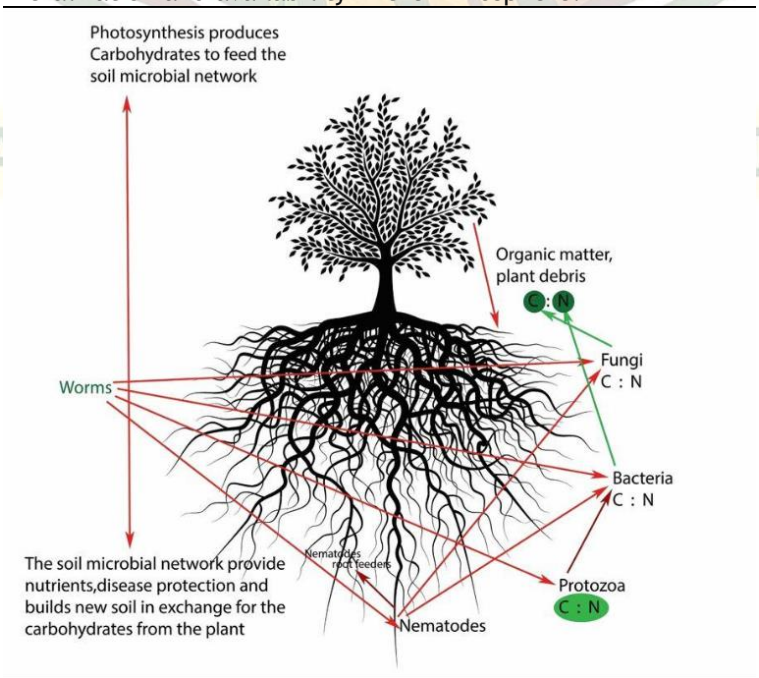
1. Expansion of Absorptive Surface Area: One of the most significant contributions of mycorrhizae is the extension of the root system through extraradical hyphae. These hyphae can penetrate soil micropores inaccessible to roots, effectively increasing the soil volume explored. This expanded network enhances nutrient interception and uptake efficiency.

2. Phosphorus Acquisition: Phosphorus is one of the most limiting nutrients in horticultural soils due to its low mobility and high fixation capacity. Mycorrhizal fungi play a central role in phosphorus acquisition by accessing phosphate beyond the depletion zone and transporting it to the plant. The fungi possess specialized phosphate transporters that facilitate efficient uptake and translocation. Mycorrhizal plants often exhibit higher phosphorus concentrations and improved growth compared to non-mycorrhizal counterparts (Smith and Read, 2011).

3. Nitrogen Uptake and Transformation: Mycorrhizal fungi contribute to nitrogen nutrition by absorbing both ammonium and nitrate forms, as well as organic nitrogen compounds. They possess enzymatic systems capable of mineralizing organic matter, thereby releasing nitrogen in plant-available forms. This is particularly important in organic and low-input horticultural systems.

4. Micronutrient Mobilization: Micronutrients such as zinc, copper, iron, and manganese are essential for plant metabolic processes but often occur in unavailable forms in soil. Mycorrhizae enhance their uptake by secreting organic acids and chelating compounds that solubilize these nutrients. This results in improved nutritional balance and plant health.

5. Enzymatic Activity and Nutrient Solubilization: Mycorrhizal fungi produce a range of enzymes, including phosphatases, proteases, and cellulases, which facilitate the breakdown of complex organic compounds. This enzymatic activity enhances nutrient mineralization and availability in the rhizosphere.



Physiological and Molecular Interactions

Mycorrhizal colonization leads to significant physiological and molecular changes in host plants. Enhanced nutrient uptake improves photosynthetic efficiency, resulting in increased carbohydrate production and biomass accumulation. These carbohydrates are partially transferred to the fungi, maintaining the symbiotic relationship. At the molecular level, mycorrhizal symbiosis involves complex signalling pathways, including the exchange of signalling molecules such as strigolactones and Myc factors. These signals regulate fungal colonization and symbiotic development. Gene expression studies have revealed the activation of specific transporter genes and stress-responsive genes in mycorrhizal plants (Smith and Read, D. J., 2008). Mycorrhizae also modulate hormonal balance by influencing the levels of auxins, cytokinins, abscisic acid, and gibberellins. This hormonal regulation contributes to improved root architecture, enhanced nutrient uptake, and better stress tolerance.

Role in Water Relations and Stress Tolerance

Mycorrhizal fungi significantly improve plant water relations by enhancing water absorption and transport. The hyphal network acts as an extension of the root system, allowing plants to access water from deeper soil layers. This is particularly beneficial under drought conditions. In addition to drought tolerance, mycorrhizae confer resistance to salinity, heavy metal toxicity, and temperature stress. They achieve this by regulating ion balance, enhancing antioxidant enzyme activity, and reducing oxidative damage.

Contribution to Soil Health and Rhizosphere Dynamics

Mycorrhizae play a fundamental role in improving soil structure and fertility. The production of glomalin, a glycoprotein secreted by arbuscular mycorrhizal fungi, contributes to soil aggregation and stability. This improves soil porosity, aeration, and water retention capacity. The interaction between mycorrhizae and other soil microorganisms creates a dynamic rhizosphere environment. Mycorrhizal fungi interact synergistically with beneficial bacteria such as plant growth-promoting rhizobacteria, enhancing nutrient cycling and plant growth.

Applications in Horticultural Crops

The application of mycorrhizal inoculants has shown promising results across various horticultural crops. In vegetable crops such as tomato, brinjal, chilli, and cucurbits, mycorrhizal inoculation improves nutrient uptake, yield, and fruit quality. In fruit crops like mango, citrus, banana, and grape, it enhances root development, nutrient acquisition, and stress resilience. In floriculture, mycorrhizae improve flowering, colour intensity, and vase life of ornamental plants. They are also widely used in nurseries to improve seedling establishment and transplant success. Berruti *et al.*, (2016) emphasized the role of mycorrhizal fungi as eco-friendly biofertilizers that can significantly reduce dependence on chemical fertilizers while maintaining crop productivity.

Interaction with Agricultural Practices

Modern agricultural practices can influence mycorrhizal efficiency. Excessive use of chemical fertilizers, particularly phosphorus, can suppress mycorrhizal colonization. Similarly, intensive tillage disrupts fungal hyphal networks, reducing their effectiveness. Conversely, practices such as organic farming, reduced tillage, crop rotation, and the use of biofertilizers promote mycorrhizal activity. Integrating mycorrhizae into sustainable horticultural systems can enhance nutrient use efficiency and environmental sustainability.

Constraints and Challenges

Despite their benefits, the application of mycorrhizae faces several challenges. Variability in field performance due to environmental conditions and soil types is a major limitation. The obligate nature of many mycorrhizal fungi makes their mass production difficult. Additionally, lack of awareness among farmers and limited availability of high-quality inoculants hinder their widespread adoption. Brundrett, (2009) highlighted the importance of proper identification and selection of compatible host–fungus combinations for successful application.

Future Perspectives

Advances in biotechnology, molecular biology, and genomics are expected to revolutionize the application of mycorrhizae in horticulture. The development of efficient inoculant formulations, understanding of plant–fungus specificity, and integration with other beneficial microorganisms will enhance their effectiveness. Research on climate-resilient mycorrhizal strains and their role in carbon sequestration and sustainable agriculture will further expand their applications. The integration of mycorrhizae into precision agriculture and smart farming systems represents a promising avenue for future research.

Conclusion

Mycorrhizae play a multifaceted role in enhancing nutrient uptake in horticultural plants through physical expansion of the root system, biochemical nutrient mobilization, and physiological regulation. Their contribution to plant growth,

stress tolerance, and soil health makes them indispensable for sustainable horticulture. The adoption of mycorrhizal technology offers a viable solution to reduce chemical inputs, improve nutrient use efficiency, and promote environmentally friendly agricultural practices. Continued research and innovation will further unlock their potential in modern horticulture.

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Intercropping: The Ancient Farming Secret That Modern Agriculture Forgot

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Mahipal[1], Santosh Korav[1]

[1]Department of Horticulture (vegetable science) School of Agriculture, Lovely professional University (Phagwara) Jalandhra-144411, Punjab.

Abstract

Intercropping, the practice of cultivating multiple crops simultaneously on the same land, is an ancient yet highly effective strategy for sustainable agriculture. This article highlights its role in enhancing productivity, improving resource-use efficiency, and strengthening ecological resilience. By combining complementary crops, particularly cereals and legumes, intercropping boosts yields, enriches soil fertility, reduces dependence on chemical inputs, and mitigates pest and disease risks. It also contributes to climate resilience and biodiversity conservation. Despite management and mechanization challenges, intercropping offers a viable alternative to monoculture systems, providing a balanced approach to achieving food security, environmental sustainability, and long-term agricultural stability.

Introduction

In the race to feed a growing global population, modern agriculture has largely leaned toward specialization—vast stretches of land planted with a single crop, managed with high inputs of fertilizers, pesticides, and machinery. While this approach has delivered impressive yields in the short term, it has also led to serious long-term challenges: declining soil health, increased pest outbreaks, biodiversity loss, and environmental degradation. Amid these concerns, an ancient agricultural practice-intercropping-is quietly re-emerging as a powerful and sustainable alternative.

What is Intercropping?

Intercropping is the practice of growing two or more crops together on the same field during the same growing season. Unlike monoculture systems, where a single crop dominates, intercropping systems intentionally combine crops that complement each other in their growth patterns, nutrient requirements, and ecological functions. This practice has been used for centuries by traditional farmers across the world, from the "Three Sisters" system (maize, beans, and squash) in the Americas to cereal-legume mixtures in Africa and Asia.

Despite its long history, intercropping has been overshadowed by industrial agriculture. Today, however, scientists and farmers are rediscovering its value—not as a relic of the past, but as a solution for the future.

Table 1: Comparison of Intercropping and Monoculture Systems:

Parameter	Intercropping System	Monoculture System
Crop Diversity	Multiple crops grown together	Single crop grown repeatedly
Yield Efficiency	Higher total productivity (LER > 1)	Limited to single crop yield
Nutrient Use	Efficient use; legumes fix nitrogen	High dependence on synthetic fertilizers
Soil Health	Improved organic matter, structure, and microbial activity	Soil degradation over time
Pest & Disease Control	Natural suppression due to crop diversity	Higher vulnerability; requires pesticides
Weed Management	Reduced weed growth due to better ground cover	Higher weed pressure
Water Use Efficiency	Better utilization and retention	Less efficient water use
Environmental Impact	Lower greenhouse gas emissions, eco-friendly	Higher emissions and environmental degradation
Climate Resilience	More resilient to drought, pests, and climate variability	High risk of total crop failure
Input Requirement	Lower chemical inputs	High input (fertilizers, pesticides)
Economic Stability	Diversified income sources	Income dependent on one crop
Management Complexity	Requires more planning and knowledge	Easier to manage
Mechanization	Limited compatibility with modern machinery	Fully compatible with machinery
Biodiversity	Enhances biodiversity (soil microbes, insects, pollinators)	Reduces biodiversity

Why Intercropping Works

The success of intercropping lies in the concept of **complementarity**. Different crops use resources—light, water, nutrients, and space—in different ways. When carefully selected and managed, these crops can coexist without intense competition, often leading to better overall productivity than when grown separately.

For example, deep-rooted crops can access water and nutrients from deeper soil layers, while shallow-rooted crops utilize resources near the surface. Similarly, tall crops can capture sunlight at higher levels, while shorter crops thrive in the filtered light below. This efficient sharing of resources increases the total output from a given piece of land.

Another key factor is **biological interaction**. Leguminous crops such as beans, peas, or cowpea have the unique ability to fix atmospheric nitrogen through symbiotic bacteria in their root nodules. This natural process enriches the soil with nitrogen, benefiting neighboring crops like maize or wheat that require high nitrogen levels. As a result, farmers can reduce their dependence on synthetic fertilizers.



Figure 1. Intercropping system (maize + legumes)

Boosting Yields Naturally

One of the most compelling arguments for intercropping is its ability to increase productivity. Studies have shown that well-designed intercropping systems often achieve higher total yields compared to monoculture systems. This advantage is measured using the **Land Equivalent Ratio (LER)**—a value greater than 1 indicates that intercropping uses land more efficiently.

For instance, cereal-legume intercropping systems frequently produce more grain and biomass per hectare than growing each crop separately. In some cases, yield increases of 20–60% have been reported. This means farmers can produce more food without expanding agricultural land—an important benefit in a world facing land scarcity and environmental constraints.

A Natural Defence System

Modern monocultures are highly vulnerable to pests and diseases because they provide a uniform and abundant food source for harmful organisms. Intercropping, on the other hand, creates a more complex and diverse environment that disrupts pest cycles.

Different crops can act as barriers, repellents, or traps for pests. For example, certain plants release natural chemicals that deter insects, while others attract beneficial predators such as ladybugs or parasitic wasps. This ecological balance reduces the need for chemical pesticides, lowering production costs and minimizing environmental harm.

Additionally, crop diversity can slow the spread of diseases. If one crop is susceptible to a particular pathogen, neigh boring crops may not be, thereby limiting the overall impact of an outbreak.

Improving Soil Health

Healthy soil is the foundation of sustainable agriculture, and intercropping plays a significant role in maintaining and enhancing soil quality. Diverse cropping systems contribute to:

1. Increased organic matter: Different crops produce varied residues that enrich the soil.

2. Better soil structure: Root systems of different shapes and depths improve soil aggregation and porosity.

3. Enhanced microbial activity: A diverse plant environment supports a wider range of beneficial soil microorganisms.

Over time, these improvements lead to better water retention, reduced erosion, and increased nutrient availability—key factors for long-term productivity.

Climate Resilience and Environmental Benefits

Intercropping is not just about productivity; it is also a climate-smart agricultural practice. By reducing reliance on synthetic fertilizers, it lowers greenhouse gas emissions associated with their production and use. Legume-based systems, in particular, can significantly cut nitrous oxide (N_2O) emissions—a potent greenhouse gas.

Moreover, intercropping systems are more resilient to climate variability. In unpredictable weather conditions, having multiple crops reduces the risk of total crop failure. If one crop performs poorly due to drought, pests, or disease, others may still thrive, ensuring some level of harvest.

The environmental benefits extend further:
1. Reduced soil erosion due to continuous ground cover
2. Improved water infiltration and reduced runoff
3. Enhanced biodiversity, including pollinators and beneficial insects

Types of Intercropping Systems

Intercropping is not a one-size-fits-all approach. Farmers can choose from several types depending on their goals, crops, and local conditions:

1. Row Intercropping: Crops are grown in distinct rows, allowing easier management and harvesting.

2. Strip Intercropping: Wider strips of different crops are planted side by side, often used in mechanized farming.

3. Relay Intercropping: A second crop is planted before the first one is harvested, ensuring continuous land use.

4. Mixed Intercropping: Crops are grown together without a specific arrangement, common in traditional systems.

Each system has its own advantages and challenges, and the choice depends on factors such as climate, soil type, and available resources.

Challenges and Limitations

Despite its many benefits, intercropping is not without challenges. One of the main barriers is **management complexity**. Farmers must carefully plan crop combinations, planting times, spacing, and harvesting methods. This requires knowledge, experience, and sometimes additional labor.

Another challenge is **mechanization**. Modern agricultural machinery is designed for monoculture systems, making it difficult to plant, manage, and harvest mixed crops efficiently. Similarly, **post-harvest processing and marketing** can be complicated, as mixed produce may require sorting and may not fit into standard supply chains.

There are also **knowledge gaps**. Many farmers are unfamiliar with intercropping techniques, and extension services may not provide adequate support. Without proper guidance, poorly designed systems can lead to competition between crops and reduced yields.

Bridging the Gap: The Way Forward

To unlock the full potential of intercropping, several steps are needed:

1. Research and innovation: Continued scientific studies to identify optimal crop combinations and management practices.

2. Farmer training and extension services: Providing practical knowledge and demonstrations to farmers.

3. Policy support: Incentives for sustainable practices, including subsidies and market support for intercropped products.

4. Technological adaptation: Development of machinery suited for diversified cropping systems.
Integrating traditional knowledge with modern science can create highly efficient and scalable intercropping systems.

Lessons from the Past, Solutions for the Future

The story of intercropping is a reminder that not all agricultural innovations are new. Sometimes, the most effective solutions have been known for generations but overlooked in the pursuit of industrial efficiency. As agriculture faces mounting challenges—from climate change to resource depletion—there is a growing recognition that sustainability must go hand in hand with productivity.

Intercropping offers a pathway to achieve both. It aligns with the principles of agroecology, working with nature rather than against it. By harnessing natural processes such as nutrient cycling, biological pest control, and plant diversity, it reduces dependence on external inputs while maintaining high productivity.

Conclusion

Intercropping is more than just an ancient farming technique—it is a resilient, efficient, and environmentally friendly approach to agriculture that holds immense promise for the future. By improving yields, enhancing soil health, reducing chemical inputs, and increasing biodiversity, it addresses many of the critical challenges facing modern farming. While barriers to adoption remain, the growing body of research and renewed interest among farmers and policymakers suggest that intercropping is poised for a comeback. With the right support and innovation, this "forgotten secret" could play a central role in building a more sustainable and secure food system.

In a world where agriculture must do more with less, intercropping stands out as a smart, practical, and time-tested solution—one that deserves to be rediscovered and widely adopted.

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Understanding Feeding Efficiency in *Helicoverpa armigera*, Larval Nutritional Indices in Agricultural Systems

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Raushan Kumar[1], Arjun Kumar Agarwal[2], Binay Kumar[1]

[1]Department of Entomology, Birsa Agriculture University, Kanke, Ranchi, Jharkhand (India)- 834006.

[2]Department of Genetics and Plant Breeding, Birsa Agriculture University, Kanke, Ranchi, Jharkhand (India)- 834006.

Introduction

Helicoverpa armigera (cotton bollworm) is a major global agricultural pest causing heavy crop losses in many regions. It feeds on a wide range of crops, including cotton, chickpea, tomato, maize, sorghum, and pigeonpea, due to its polyphagous nature, high reproduction, migration ability, and insecticide resistance. Its larval stage is especially destructive, damaging leaves, buds, flowers, and fruits. Studying larval feeding through nutritional indices helps measure how efficiently the insect consumes and converts food into growth. These indices are important for understanding pest biology and developing effective integrated pest management (IPM) strategies.

Concept of Larval Nutritional Indices

Larval nutritional indices are derived from gravimetric and biochemical measurements that quantify food utilization by insect larvae. These indices help in assessing the relationship between food intake, digestion, and growth. The foundational work by Waldbauer (1968) established standardized formulas that are widely used in insect nutritional ecology.

The primary indices include:

1. Consumption Index (CI): Consumption Index represents the rate at which food is consumed relative to the average body weight of the larva over a given time period. It is expressed as:

CI = Food Consumed / (Mean Larval Weight × Time)

A higher CI indicates increased feeding activity, which may reflect compensatory feeding when food quality is low.

2. Growth Rate (GR): Growth Rate measures the increase in larval biomass over time:

GR = Weight Gain / (Mean Larval Weight × Time)

This index reflects the overall physiological performance of the larva under specific dietary conditions.

3. Approximate Digestibility (AD): Approximate Digestibility indicates the proportion of ingested food that is digested rather than excreted:

AD (%) = [(Food Ingested − Faeces Produced) / Food Ingested] × 100

High AD values suggest efficient digestion, although not necessarily efficient conversion into biomass.

4. Efficiency of Conversion of Ingested Food (ECI): ECI measures how efficiently consumed food is converted into body mass:

ECI (%) = (Weight Gain / Food Ingested) × 100

This index integrates both digestive and metabolic efficiency.

5. Efficiency of Conversion of Digested Food (ECD): ECD reflects the efficiency with which digested food contributes to growth:

ECD (%) = (Weight Gain / (Food Ingested − faeces)) × 100

It provides insight into post-digestive metabolic processes.

Methodology for Nutritional Indices Analysis

The analysis of larval nutritional indices involves controlled laboratory experiments. Typically, newly moulted larvae are reared individually on specific host plant materials or artificial diets. The experimental setup includes precise measurement of:

1. Initial and final larval weights
2. Amount of food provided and consumed
3. Weight of faecal matter produced
4. Duration of the feeding period

Environmental conditions such as temperature, humidity, and photoperiod are maintained consistently to minimize variability. The collected data are then used to calculate the indices using standard formulas.

Modern studies may also incorporate biochemical assays, such as enzyme activity measurements (e.g., proteases, amylases, lipases), to complement traditional nutritional indices.

Factors Influencing Nutritional Indices in *H. armigera*

1. Host Plant Quality: Host plant species and varieties significantly influence larval feeding efficiency. Plants differ in their nutritional composition, including protein, carbohydrate, lipid, and micronutrient content. For example, larvae feeding on protein-rich hosts often exhibit higher growth rates and ECI values.

Conversely, plants with defensive traits such as high fibre content, tough tissues, or secondary metabolites can reduce feeding efficiency. Resistant crop varieties often result in lower CI, GR, ECI, and ECD values.

2. Plant Secondary Metabolites: Secondary metabolites such as alkaloids, phenolics, tannins, and terpenoids play a crucial role in plant defence (Koul *et al*., 2004). These compounds can:

a. Reduce palatability
b. Interfere with digestion
c. Inhibit enzyme activity
d. Increase metabolic costs

As a result, larvae may show increased CI (compensatory feeding) but reduced ECI and ECD, indicating inefficient utilization of food.

3. Environmental Factors: Temperature, humidity, and photoperiod influence insect metabolism and feeding behaviour. For instance:

a. Higher temperatures may increase metabolic rates, leading to higher CI and GR.
b. Extreme conditions can reduce digestive efficiency and survival.

Climate change is expected to alter these dynamics, potentially affecting pest outbreaks and crop damage patterns.

4. Insect Developmental Stage: Nutritional indices vary across larval instars. Early instars typically have lower consumption rates but higher efficiency of conversion, while later instars consume more food but may show reduced efficiency due to increased maintenance energy costs.

5. Exposure to Insecticides and Biopesticides: Sub-lethal exposure to insecticides can significantly affect feeding behaviour and metabolism (Ahmad and Ansari, 2010). Nutritional indices are useful for detecting such effects:

a. Reduced CI and GR may indicate feeding deterrence.
b. Lower ECI and ECD suggest metabolic disruption.

Biopesticides, such as *Bacillus thuringiensis* (Bt), often reduce digestive efficiency, leading to decreased larval growth.

Applications in Agricultural Science

1. Host Plant Resistance Screening: Nutritional indices are widely used to evaluate crop resistance against *H. armigera*. Resistant varieties typically result in:

a. Lower consumption and growth rates
b. Reduced conversion efficiencies
c. Increased larval mortality

Such information is critical for plant breeding programs aimed at developing pest-resistant cultivars.

2. Integrated Pest Management (IPM): Understanding larval feeding efficiency helps optimize IPM strategies. For example:

a. Crops that reduce larval growth can suppress pest populations naturally.
b. Timing of control measures can be aligned with periods of maximum feeding activity.

3. Evaluation of Pest Control Agents: Nutritional indices provide a sensitive measure of the effectiveness of insecticides and biopesticides. They help detect sub-lethal effects that may not be immediately visible through mortality data alone.

Challenges and Limitations

Despite their usefulness, nutritional indices have certain limitations:

1. Laboratory conditions may not fully represent field environments.
2. Variability in experimental methods can affect comparability.
3. Indices provide indirect measures and may not capture all physiological processes.

Therefore, they should be used in conjunction with other ecological and biochemical studies for comprehensive analysis.

Conclusion

Larval nutritional indices analysis helps explain how *Helicoverpa armigera* feeds, digests, and converts food into growth, offering key insights into its adaptability and impact on different crops. It is widely used in pest management and crop

resistance studies. With rising challenges like insecticide resistance and climate change, this approach supports the development of more sustainable and eco-friendly pest control strategies.

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